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HEART RATE AND RESPIRATORY RATE DURING FITNESS TRAINING, OBSTACLE COURSE RUNS, AND MASS CASUALTY SIMULATIONS - PERFORMANCE OF TWO WARFIGHTER PHYSIOLOGICAL STATUS MONITORING SYSTEMS

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14. ABSTRACT

The U.S. Army Medical Department Board conducted a Customer Assessment of the Warfighter Physiological Status Monitor (WPSM) under USAMEDDBD Project 17-07, during July 23 – 27, 2007 at Camp Bullis, TX . The assessment primarily focused on whether WPSM triage information and use models proved beneficial to medics in assessing and providing care to simulated casualties, and examining the form and fit of two potential WPSM monitors. In addition during the customer assessment physiological data were collected by the two WPSM candidate monitors. The goal of this technical report is to provide a very quick analysis of the physiological data to aid the manufacturers as they continue to develop systems for field use.

15. SUBJECT TERMS

WPSM, Warfighter Physiological Status Monitoring, Vital Signs, Ambulatory Physiological Monitoring, Heart Rate, Respiration Rate, Shirt, Chest Belt, Vital Sign Detection System.

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EXECUTIVE SUMMARY

The U.S. Army Medical Department Board, conducted customer assessments of two candidate Warfighter Physiological Status Monitor (WPSM) vital sign detection systems (VSDS) under USAMEDDBD Project 17-07, from July 23 – 27, 2007 at Camp Bullis, Fort Sam Houston, Texas. One WPSM VSDS system was in the form of a shirt (Foster Miller, Inc., Combat Shirt), and the other was in the form of a chest belt (Hidalgo Ltd, Equivital system).

The customer assessments primarily focused on (a) how medics might use WPSM VSDS information to triage and provide care to simulated casualties, (b) whether medics found WPSM VSDS information to be of value in the triage and casualty care process, and (c) whether the quality of the form and fit of the two candidate WPSM VSDS monitors was acceptable. In addition, (e) physiological data were collected by the two candidate WPSM VSDS monitors during the customer assessments. This technical report provides an initial analysis of the quality of physiological data provided by the two candidate WPSM VSDS systems.

Two candidate WPSM vital signs detection systems (VSDS) were used in the customer assessment performed by the U.S. Army Medical Department Board (USAMEDDBD). Physiological data were collected during the study using four (4 ea) Foster Miller (shirts) and five (5 ea) Hidalgo (chest belt) systems.

The Foster Miller system successfully provided data for about 70% of the of the study and the Hidalgo system for about 94% of the study. Of the collected data the Foster Miller shirt provided data that represented reasonable physiology 66% of the time for heart rate and 51% of the time for respiration rate. The loss of data appeared to be due to loose fitting shirts. Of the Hidalgo data reasonable heart rates were collected for almost all the time (>98%) and reasonable respiration data for about 70% of the time. Loss of respiration data by the Hidalgo system appeared to be due to respiration sensor breakage from overextension during donning.

Those instances where data loss occurred or where data quality was unacceptable could be attributed to technical reasons such as failure of ancillary data logging device, improper fit, and subcomponent breakage. Resolution of these tractable technical issues should result in WPSM VSDS systems that are capable of reliably collecting acceptable heart rate and respiration rate data from warfighters in the field.

INTRODUCTION

The United States Army Medical Research and Materiel Command (USAMRMC) is developing a warfighter physiological status monitoring (WPSM) capability for both combat casualty care and military operational medicine. As part of this process, the U.S. Army Medical Department Board (USAMEDDB) conducted customer assessments of two candidate Warfighter Physiological Status Monitor (WPSM) vital sign detection systems (VSDS). The customer assessments were performed under USAMEDDBD Project 17-07, from July 23 – 27, 2007 at Camp Bullis, Fort Sam Houston, Texas. Two candidate WPSM VSDS systems were evaluated; one was in the form of a shirt (Foster Miller, Inc., Combat Shirt), and the other was in the form of a chest belt (Hidalgo Ltd Equivital system).

The WPSM – Initial Capability (WPSM-IC) Army Technology Objective (ATO), completed in FY 2006, developed an integrated soldier-worn system consisting of sensors and algorithms that provides medics and commanders with remote health status information. Health status information includes vital signs (heart rate, respiration), skin temperature, fluid intake, sleep history, and detection of ballistic impact (1,2). This system was demonstrated during a two week training exercise at Aberdeen Proving Ground, MD, and as part of the Future Force Warrior (FFW) component of the On The Move (OTM) experiment at Fort Dix, NJ. In response to guidance from the U.S. Army Medical Department Center and School (AMEDDC&S), the ATO work effort focused on developing a mature (Technology Readiness Level = 6: Prototype tested in a relevant environment) vital sign detection capability. The USAMRMC used a three-tiered approach to developing a WPSM capability:

Tier 1: Vital Sign Detection System (VSDS) – device must accurately and reliably determine the absence of vital signs. The device must provide an alert when there has been no heart rate, no respiration rate, and no physical activity for more than five minutes. The device must perform self-checks to confirm that the system is being worn in the correct fashion and that the electronic components of the sensor system are functioning correctly.

Tier 2: Advanced Remote Triage – add advanced triage capabilities to WPSM system to include wound detection and algorithms to predict vital sign and health state trends.

Tier 3: Thermal State Management – add capability to assess and predict thermal state and prevent/reduce the number of heat casualties.

During the course of the ATO the WPSM-IC program invested money and collaboratively worked with three vendors to develop a wearable vital sign detection system capable of measuring heart rate, respiration rate and activity. The three systems were developed by Foster Miller Inc. (Waltham, MA), Hidalgo Ltd (Cambridge, UK), and Vivometrics (Ventura, CA).

Although potential Tier 1 vital sign detection systems existed, it was unclear whether remote physiological monitoring and, more specifically, remote vital sign and health state would be useful to medics. To address this question, the USAMEDDBD was asked to conduct a customer assessment to answer the question: Does having WPSM health state assessment information enhance a medic's capability to triage and treat casualties?

This assessment was conducted under USAMEDDBD Project 17-07, during July 23 – 27, 2007 at Camp Bullis, located at Fort Sam Houston, Texas. Two candidate WPSM VSDS systems were evaluated; one in the form of a shirt (Foster Miller, Inc., Combat Shirt), and the other in the form of a chest belt (Hidalgo Ltd Equivital system).

The USAMEDDBD evaluation primarily focused on (a) how medics might use WPSM VSDS information to triage and provide care to simulated casualties, (b) whether medics found WPSM VSDS information to be of value in the triage and casualty care process, and (c) whether the quality of the form and fit of the two candidate WPSM VSDS monitors was acceptable. In addition, (e) physiological data were collected by the two candidate WPSM VSDS monitors during the customer assessments. The triage information assessment and user form and fit data are reported in a memorandum report USAMEDDBD Project 17-07 dated 13 August 2007. This technical report provides an initial analysis of the quality of physiological data provided by the two candidate WPSM VSDS systems.

METHODS

VOLUNTEERS

Ten (2 female and 8 male) initial-entry training students from the Academy of Health Sciences (AMEDDC&S) participated in the study.

EQUIPMENT

<u>Foster Miller Inc. (Waltham, MA)</u>

Figure 1 shows the Foster Miller "Watchdog" vital sign detection system (VSDS) shirt worn during this customer assessment. The shirt logged heart rate, respiration rate, skin temperature and activity data once every 15 seconds to internal memory for later download. The internal memory could hold approximately 4 hours of data. Data were downloaded at the end of the day or for long training sessions data were downloaded at the break and at the end of the day. (http://www.foster-miller.com/literature/documents/DS07-023-WatchdogTactical.pdf)

Figure 1. Foster Miller Inc. shirt VSDS

Hidalgo Ltd. (Cambridge, UK)

Figure 2 shows the Hidalgo "Equivital" (http://www.equivital.co.uk/) vital sign detection chest belt worn during the customer assessment. The belt transmitted data to a Hewlett Packard iPaq HX2490 personal digital assistant (PDA) via a standard Bluetooth radio frequency (RF) link. The PDA logged data to a micro secure digital (μSD) card with a capacity of 1GB. Waveform data for two channels of ECG (256 Hz), respiration (25.6 Hz), and 3 channels of accelerometer (25.6 Hz) data were logged along with 15 second summary data of heart rate, respiration rate, skin temperature, and activity. Data were logged at a rate of 6.5 Mega bytes per hour.

Figure 2. Hidalgo Ltd. belt VSDS

DESIGN

The customer assessment took place over five days as shown in Table 1.

Table 1. Capability Assessment Test Schedule of Activities

Day	Activity	Description
1	Diagnostic Army Physical Fitness Test (DAPFT)	2 minute of sit ups and push ups, timed two mile run.
2	Obstacle Course, Trauma Lane	Wearing either a fragmentation vest (10 lbs) or Interceptor body armor (32 lbs)
3	Diagnostic Army Physical Fitness Test (DAPFT)	2 minute of sit ups and push ups, timed two mile run.
4	Obstacle Course, Trauma Lane	Wearing either a fragmentation vest (10 lbs) or Interceptor body armor (32 lbs)
5	Investigative Excursion	Several additional Trauma Lane scenarios

Volunteers were divided into two equal groups. During days 1 and 2, group 1 wore the Foster Miller VSDS and group 2 wore the Hidalgo VSDS. During days 3 to 5, group 1 wore the Hidalgo VSDS and group 2 the Foster Miller VSDS. At the beginning of each day, baseline heart rates and respiration rates were obtained by the medic manually counting beats and breaths (radial pulses and chest rise and fall). On days 1 and 3 during the DAPFT, additional heart and respiration rates measurements were made using manual methods at 1 min after completing the prescribed sit ups, push ups, and the 2 mile run, as well as at the 1 mile mark of the run.

PROCEDURES

At the beginning of day 1 and 3 volunteers were sized based upon manufacturer instructions and issued VSDS systems that provided the best fit possible. However, due to a limited supply of VSDS devices a correct fit could not be made every time. Manufacturer donning instructions and training were provided, but volunteers were left to don the systems independently. All VSDS systems were hand washed each evening, but each subject kept the same VSDS over the two or three days of testing for that system. Once the shirt or belt was donned the electronic sensor modules were turned on and connected. For the Foster Miller VSDS, the act of connecting the sensor module to the shirt activated and initialized the device. For the Hidalgo VSDS the device was initially turned on and initialized. If the device sensed the belt was “on-body” the device would provide a series of three pager-style buzzes, and establish a Bluetooth^tm connection to the PDA. On test days 2, 4 and 5, the Foster Miller system was stopped and downloaded during the break between exercises. At the end of each days events systems were collected and downloaded to a personal computer (PC).

MEASURES

The VSDS system capability to provide physiological information was rated based on the ability to (a) collect and record data for a given period of time, and (b) the quality of the data collected.

The quality of available heart rate and respiration rate data was assessed in two ways. First, data taken by the medic by counting heart rate and breathing rate (radial pulse and chest rise and fall) was compared to that measured by the VSDS systems. Most rates were calculated by counting beats/breaths for 15s and then multiplying the counts by 4. This method leads to an error margin of ± 4 beats or breaths per minute. Thus in the analysis devices were credited with a correct beat or breath if they were within ± 4. As timing between medic-measured rates and device-measured rates could not be precisely aligned, the best match of between medic-measured rate and VSDS-measured rate was selected within a ± 2 min window of the medic-reported time.

The time series data for each subject for each test day was examined to identify any unusual or non-physiologic data. This examination was guided by determining physiologically reasonable ranges from data taken from the USARIEM VSDS lab validation study (3) gold standard data. The minimum thresholds for heart rate and respiration rate were derived from the gold standard heart/respiration rate monitor data collected during the sitting condition, while the maximum thresholds were derived from the gold standard heart rate data from the running condition.

The physiologically acceptable range is calculated for both heart and respiration rates from the gold standard data in the following way. The minimum HR or respiratory rate was calculated as the minimum observed during the sitting condition minus two standard deviations (SD), and the maximum observed during running condition plus two SDs.

$$Rate_{\min} = Rate_{sitting}^{value} - (2 \times Rate_{sitting}^{SD})$$

$$Rate_{\max} = Rate_{running}^{value} + (2 \times Rate_{running}^{SD})$$

Rounded values of the minimum and maximum rates are used. Table 2 shows the mean heart and respiration rate values and standard deviations for subjects sitting and running in the VSDS validation study and the ranges used in the current data analysis.

Table 2. Calculated Heart and Respiration Rate Acceptable Range Values

	Sitting		Running		Range	
	Value	SD	Value	SD	Min	Max
Heart Rate (Mean)[1]	73.7	6.6	152.9	15.7	61	184
Respiration Rate (Mean)[1]	16.0	2.1	38.2	6.1	12	50

[1] Mean and SD for Heart and Respiration Rate taken as a mean of all subjects with all data points from the condition.

Mean heart and respiration rate data from the laboratory validation study was also used as a guide to provide typical values for a number of activities. Table 3 presents mean heart and respiration rate gold standard values from the laboratory validation study for a number of activities. The amount of “acceptable” data was rounded to the nearest 5% and reported for each subject for each day.

Table 3. Laboratory Validation Study Mean Heart and Respiration Rate Values for Different Activities

	Heart Rate (BPM)		**Respiration Rate (Breaths per Min)**	
Condition	**mean**	**SD**	**mean**	**SD**
Prone	73.0	8.1	16.8	2.5
Supine	69.6	6.5	17.6	3.0
Sitting	69.3	6.1	15.8	2.9
Standing	78.6	5.9	16.6	2.2
Walking	93.8	6.6	23.8	3.2
Calisthenics	123.6	10.7	31.0	3.8
Running	153.3	9.2	37.9	7.7

RESULTS

DATA AVAILABILITY

Table 4 presents the percentage of available data for the Foster Miller system for each test day, and table 5 presents the percentage of available data for the Hidalgo system for each test day.

Table 4 Percentage Data Availability for Foster Miller WPSM System

Subject ID	Data Availability (%) 07/23	07/24	07/25	07/26	07/27
1	X	X			
2	100	50			
3	100	0			
4	100	50			
5	100	50			
6			100	100	50
7			0	50	50
8			100	50	100
9			X	X	X
10			100	100	100

X = Subject did not participate in test.
2. PDA Turned Off.

Table 5 Percentage Data Availability for Hidalgo WPSM System

Subject ID	Data Availability (%) 07/23	07/24	07/25	07/26	07/27
1			100	100	100
2			100	100	100
3			100	100	100
4			50[2]	100	100
5			10[2]	100	100
6	100	100			
7	100	100			
8	100	100			
9	100	X			
10	100	100			

X = Subject did not participate in test.

On average the Hidalgo system provided test data for 94% of the test time while the Foster Miller provided test data for 73% of the test time. In terms of logging attempts data were successfully fully logged and downloaded 92% and 72% for Hidalgo and Foster Miller respectively.

COMPARISON OF MANUAL RATES TO VSDS RATES

Table 6 presents the comparison of medic taken heart and respiration rates to the VSDS recorded rates. Column one shows the number of available medic taken rates. Where medics did not record a time for a rate it was not included in this total. Column two indicates the number of points where the VSDS was able to provide data. Column three presents the number of VSDS points that fall within ± 4 beats or breaths within ± 2 minutes of the medic time; this is represented as a percentage in column four.

Table 6 Comparison of Medic-Reported Heart and Respiration Rates with VSDS Recorded Rates

		VSDS	1. Medic N	2. VSDS N	3. N within ± 4	4. % Within ± 4
Baseline - All Days	HR	FM	36	29	9	31
		H	46	41	25	61
	VE	FM	36	29	11	38
		H	49	41	30	73

White Cells = Foster Miller System, Gray Cells = Hidalgo System.
HR = Heart Rate
VE = Respiration Rate
FM = Foster Miller System
H = Hidalgo System

Overall the Hidalgo system “matched” the medic rates for 61% for heart rate and 72% for respiration rate. The Foster Miller system “matched” 31% of the heart rates and 38% of the respiration rates.

SUBJECTIVE ANALYSIS OF TIME HISTORY PLOTS

The time history plots of data for each subject for each test day are presented in Appendix A. Table 7 presents the percentage of data that seems physiologically reasonable from the first two-day trial. Table 8 presents the percentage of data from the second two-day trial and the final day investigative excursion.

Table 7 Subjective Percentage of Physiologically Reasonable Heart and Respiration Rates of the VSDS Systems for Days 1-2

Date	Subject	VSDS	HR (%)	VE (%)	Comments
07/23	1	X	X	X	X
	2	FM	90	0	No resp. HR lost during run
	3	FM	0	100	No HR
	4	FM	50	100	HR missing during exercise
	5	FM	100	100	
	6	H	100	0	No resp.
	7	H	100	90	Resp. low ~5%
	8	H	100	0	No resp.
	9	H	100	100	
	10	H	100	100	
07/24	1	X	X	X	X
	2	FM	100	100	Resp. seems high (not often below 20).
	3	FM	N	N	No data collected.
	4	FM	40	0	No resp. HR Lost for 1st 60%
	5	FM	100	100	Resp. seems high (not often below 20).
	6	H	100	100	
	7	H	100	0	No resp.
	8	H	100	100	
	9	X	X	X	X
	10	H	100	100	

White Cells = Foster Miller System, Gray Cells = Hidalgo System.
X = Subject did not participate in test
N = The system did not log data
FM = Foster Miller
H = Hidalgo
HR = Heart Rate (BPM)
VE = Ventilation Rate (Br. /Min.)

Table 8 Subjective Percentage of Physiologically Reasonable Heart and Respiration Rates of the VSDS Systems for Days 3-5

Date	**Subject**	**VSDS**	**HR (%)**	**VE (%)**	**Comments**
07/25	1	H	100	100	
	2	H	100	70	Resp. low ~30%
	3	H	100	100	Resp. low?
	4	H	100	100	
	5	H	100	100	
	6	FM	100	0	No resp.
	7	FM	N	N	No data collected
	8	FM	100	100	Resp. seems high (not often below 20).
	9	X	X	X	X
	10	FM	5	0	No resp. Only ~5% HR.
07/26	1	H	100	100	
	2	H	90	5	Resp too low. HR noisy 1st 50%.
	3	H	100	100	
	4	H	100	50	Resp low ~50%, Some HR noise.
	5	H	100	0	Resp. low.
	6	FM	100	100	
	7	FM	50	90	~10% of resp. is a straight line. Resp. high (not often below 20).
	8	FM	100	0	Resp. is too high. Never below 30.
	9	X	X	X	X
	10	FM	10	50	Resp is mostly too high. Very little HR.
07/27	1	H	100	100	
	2	H	100	100	
	3	H	100	100	
	4	H	100	100	
	5	H	100	0	Resp. is too low.
	6	FM	70	0	Resp. is almost straight line at 46 Br. / Min.
	7	FM	75	0	Resp. values are too high only 17 individual points below 40 Br. / Min.
	8	FM	90	0	Resp. seems very high. HR seems high.
	9	X	X	X	X
	10	FM	10	75	Resp. rate in some parts is high.

White Cells = Foster Miller System, Gray Cells = Hidalgo System.
X = Subject did not participate in test
N = The system did not log data
FM = Foster Miller
H = Hidalgo
HR = Heart Rate (BPM)
VE = Ventilation Rate (Br. /Min.)

Table 9 shows the overall percentage of data that reflected physiologically reasonable heart rates and respiration rates.

Table 9 Overall Approximate Percentage of Physiologically Reasonable Data from Both VSDS Systems

System	Mean amount of physiologically reasonable data (%, Approx.)	
	Heart Rate	Respiration Rate
Foster Miller	65.5	50.8
Hidalgo	99.6	71.5

Overall the Foster Miller VSDS was able to provide data that seemed physiologically reasonable for 66% of the time for heart rate and 51% of the time for respiration rate. The Hidalgo VSDS was able to provide data that seemed physiologically reasonable for almost all of the time and about 71% of the time for respiration data.

DISCUSSION

The VSDS performance differed between vendor systems for different reasons. Each system and its performance will be addressed individually.

FOSTER MILLER VSDS

Data Availability

The Foster Milller VSDS was only able to log or download about 70% of the required data. The 30% loss of data came from sessions where data would not download through the Bluetooth communications link. It is unclear whether data existed and could not be downloaded or that no data existed. One possible explanation may come from the fact that the system is designed to power on when the electronics are connected to the shirt and power down when disconnected. Powering down has the unfortunate consequence of loosing logged data. Changing this functionality such that data can be accessed after power down may prevent data loss from user error or momentary power cycles.

Data Quality

The Foster Miller VSDS had periods when it collected good quality heart rate and respiration rate data, and periods when data were of poor quality or did not exist. For heart rate, the subjective analysis of the data shows only about 67% of data to be physiologically reasonable. Most of the periods where the data were outside of the physiologically reasonable range showed either that a heart rate was undetermined (e.g. Appendix A, Chart Subject 03, 07/23/07) or jumped rapidly from no reported value to some heart rate (e.g. Appendix A, Chart Subject 04, 07/24/07). Medic-measured heart rates corresponded to those measured by the Foster Miller 31% of the time.

Compared to heart rate measurements, respiration rate was measured with less success, only providing 50% “good” quality data. Much of the respiration data loss was from either whole sessions where respiration was not reported (e.g. Appendix A, Chart Subject 06, 07/25/07) or where the absolute respiration value was too high for the given activity and respiration acted in a linear fashion (e.g. Appendix A, Chart Subject 06, 07, and 08, 07/27/07). Medic-estimated respiration rates corresponded to those measured by the Foster Miller system 38% of the time. Notably, three of the four Foster Miller VSDS shirts are providing unusually high respiration data and acting in a linear fashion on the last day of testing. This may indicate a progressive failure within the shirt or hardware.

The relatively poor performance of both the heart rate and respiration rate sensors may be in part due to the limited number of shirts and shirt sizes available for testing. This meant that not all subjects could be fitted correctly, thus leaving either a tight or loose fit with no means of adjustment to the individual. The shirt was also not originally designed for females, and the correct fitting of the two female subjects may have been an issue. In cases where the fit was loose it is conceivable that no respiration signal would have been read. This theory is consistent with some of the data where no respiration signal is present.

Generally, medic- and VSDS-measured rates may not correspond due to the fact that the time at which medics made their measurements is approximate and not time synchronized with the VSDS devices. Thus there can be some periods where the VSDS data do not match medic data because of time synchronization issues.

HIDALGO VSDS

<u>Data Availability</u>

The Hidalgo VSDS was able to provide data for 94% of the experiment. The six percent of the time where data were not recorded can be attributed to technical issues related to the data logging method. The Hidalgo VSDS used in this study did not have internal memory. Data logging was accomplished through a Bluetooth wireless link to a PDA. Data were lost from two subjects when the PDA’s were inadvertently switched off. It cannot be determined if the PDA’s powered down due to the battery connection issues or whether the power buttons were pressed accidentally by the users or other equipment.

<u>Data Quality</u>

The Hidalgo VSDS heart rate data quality appeared to be acceptable with most of the heart rate data within expected bounds. There are a few periods where the data appear somewhat noisy (e.g. Appendix A, Subject 02, 0726/07), but this is often at the start of the session where the belt electrodes may be drier and thus more susceptible to motion artifact.

In comparing the VSDS heart rates to the medic-measured heart rates, the Hidalgo system “matched” 61% of the points. While this performance is not as good as

the subjective analysis the lower performance may be explained somewhat by the approximate measurement times reported by the medics.

The respiration rate sensing did not perform as well as the heart rate sensing, appearing to provide only about 70% “good” quality data. Most of the “poor” data were from sessions where the respiration rate was either 0 or very low for the whole session (e.g. Appendix A, Chart Subject 07, 07/24/07). Similar performance was observed in the number of rates that matched the medic taken respiration rates, with 71% within the ± 4 breaths window.

A majority of the poor respiration data appeared to be due to two belts where the respiration component of the belt was found to not be functioning. It is possible that these belts were broken on the first day by volunteers not understanding how to don the belts. During the first day of testing a number of volunteers donned the belt in a similar fashion to donning a t-shirt. This donning technique has in the past caused the respiration portion of the belts to malfunction or break entirely.

CONCLUSIONS

Both VSDS systems were able to collect good quality data for a majority of the testing sessions. Data were lost or poor for a number of technical reasons including: functional failure of logging device, improper fit, and belt component breakages. Fixing these avenues of failure would suggest that good quality heart rate and respiration rate data can be collected successfully and cleanly for similar events in the future.

RECOMMENDATIONS

- In future studies the fit and donning of the devices should be considered more closely. Volunteers should be trained in the proper method of donning systems.
- For the Foster Miller shirt some form of adjustment should be added to ensure proper sensor fit to the wearer. The logging malfunction of the system should be addressed so that data are not lost when the device is power cycled.
- For the Hidalgo belt, the failure of the respiration portion of the belt should be examined to identify the failure modes when the belt is hyper-extended. Corrections should be made to the design to prevent failures of this kind.

REFERENCES

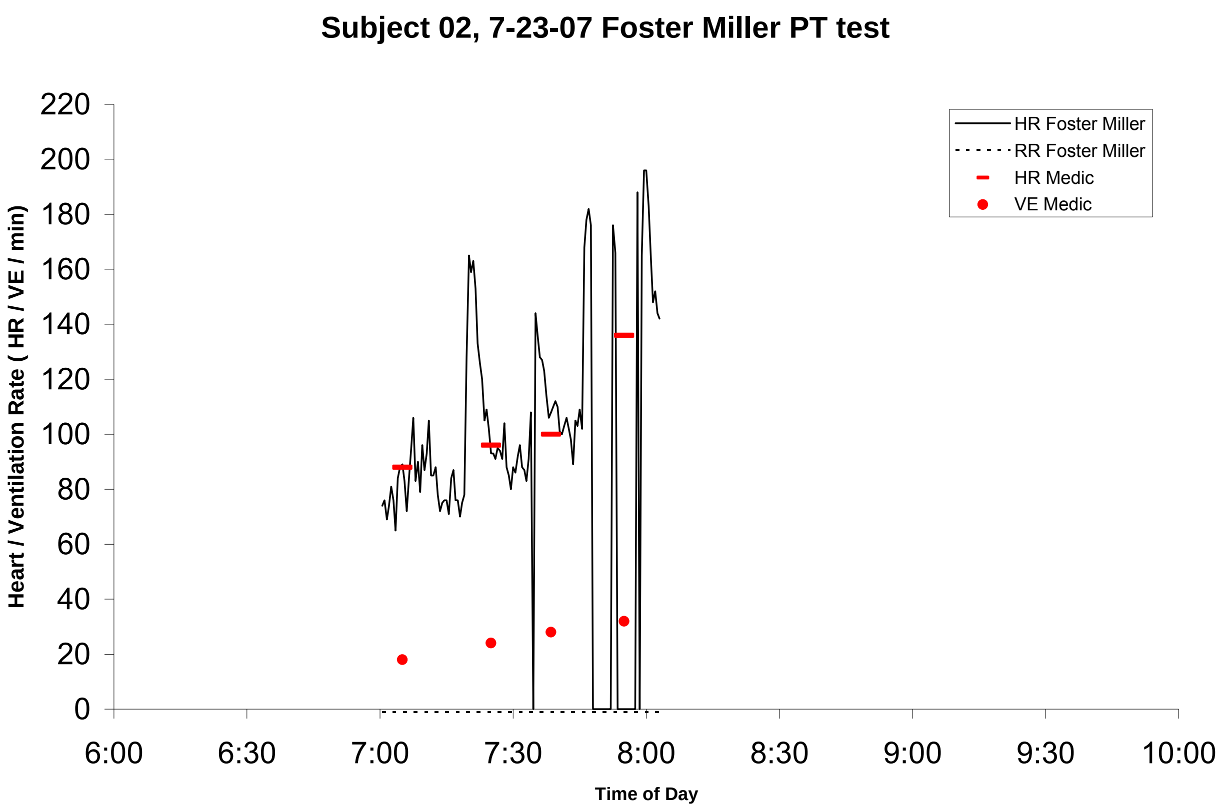
1. Tharion, W. J., M. J. Buller, A. J. Karis and S. P. Mullen. Acceptability of a wearable vital sign detection system. *Proceedings of the Human Factors Society 51st Annual Meeting*. Human Factors and Ergonomics Society, Santa Monica CA. Volume 51, 2007.

2. Buller, M. J., R. W. Hoyt, J. S. Ames, W. A. Latzka, B. J. Freund. Enhancing warfighter readiness through situational awarness – the Warfighter Physiologic Monitoring – Initial Capability. *11th International Conference on Human-Computer Interaction Proceedings*, Las Vegas, July 2005 (Augmented Cognition). Lawrence Erlbaum Associates, Inc (ISBN 0-8058-5807-5)

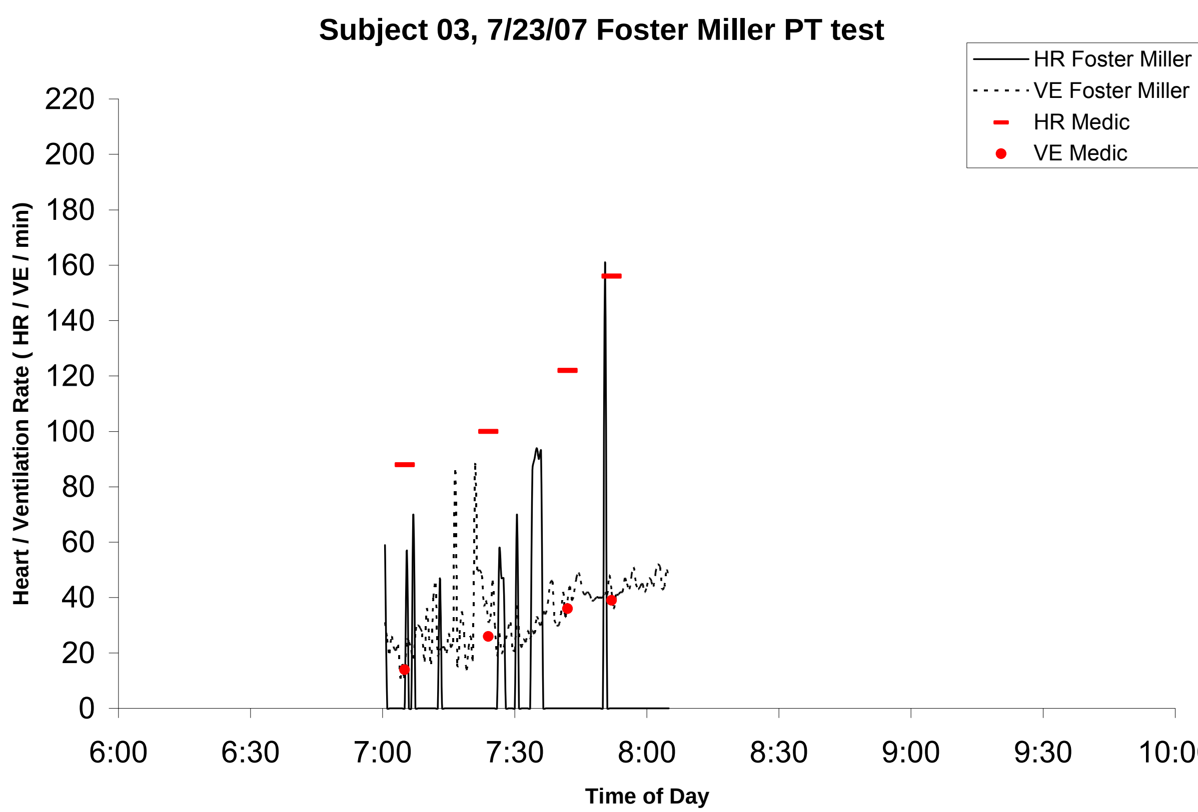
3. Tharion, W. J., M. J. Buller, A. J. Karis, S. M. Kaushik, W. A. Latzka and B. J. Freund. Warfighter Physiological Status Monitoring (WPSM) reliability and validation test of the Hidalgo Equivital Vital Signs Detection System (VSDS). HURC #H05-09, 2005.

APPENDIX A

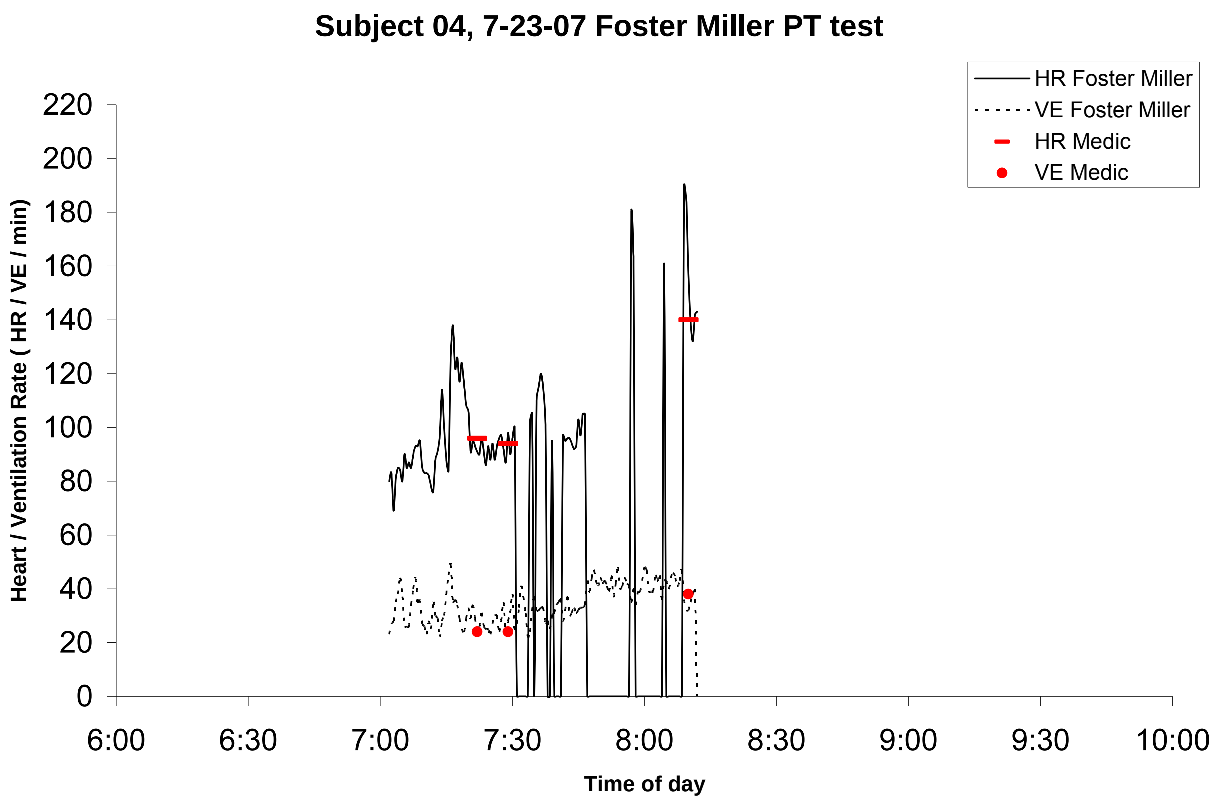
Time series data plots for each subject for each day of the exercise. Medic-measured heart rates and respiration rates are also plotted on each chart. On days when medics took only baseline readings in the morning, solid lines denote the measurement level extended over the course of the entire day. Please note that the data sets presented may contain periods before and after the system is worn when no data was collected.

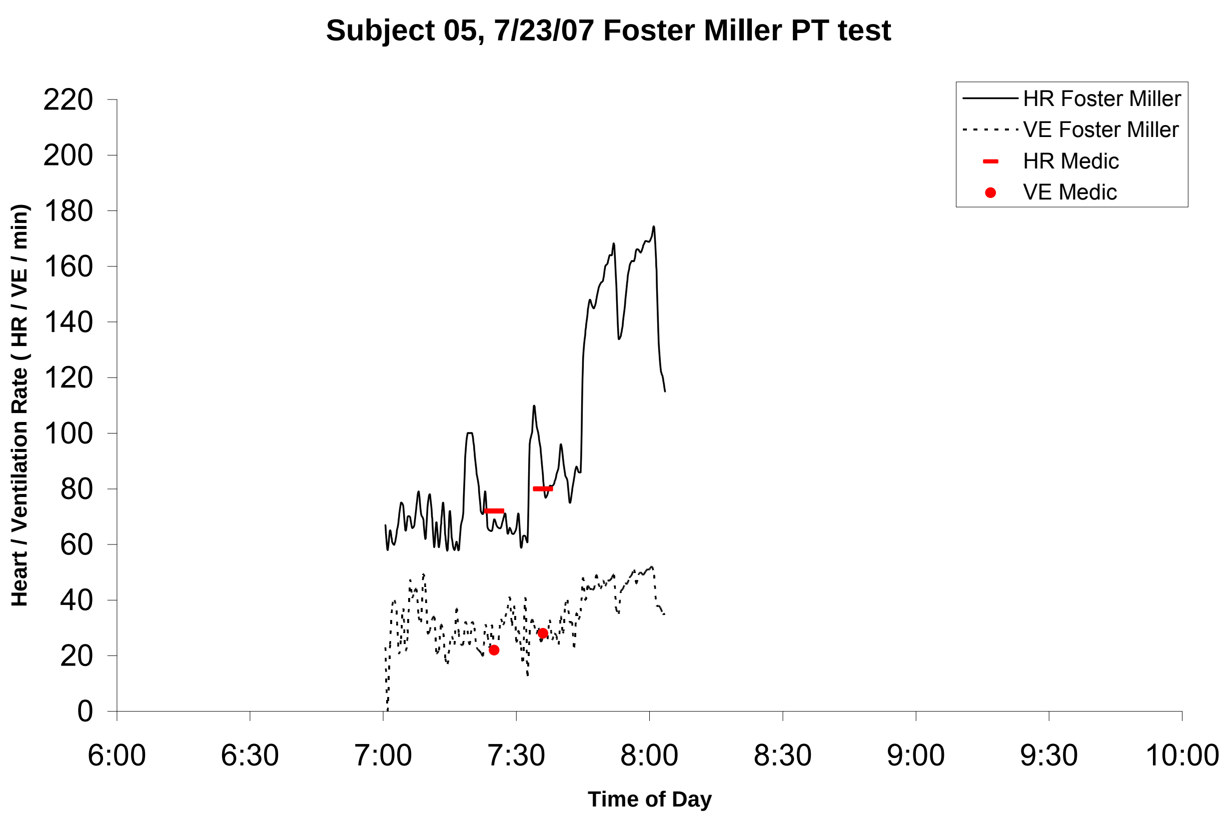


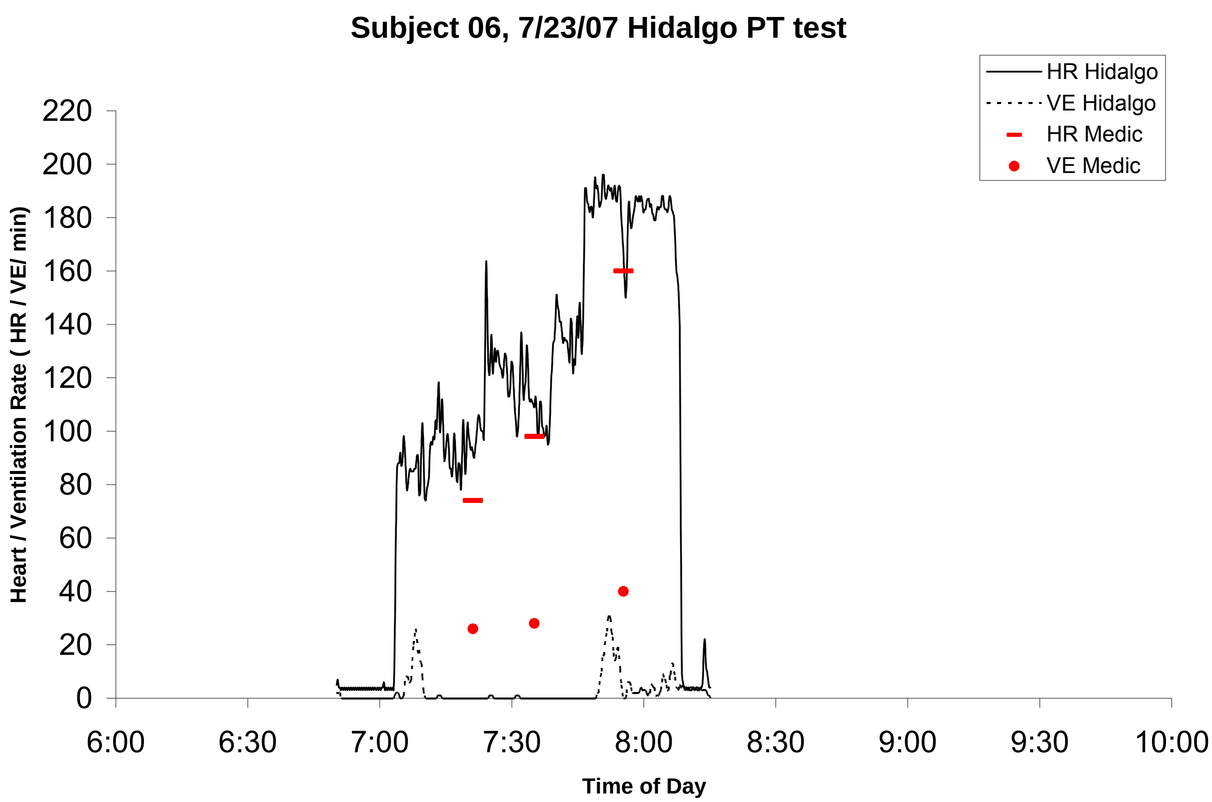
Subject 02, 7-23-07 Foster Miller PT test
Heart / Ventilation Rate (HR / VE / min)
Time of Day
HR Foster Miller
RR Foster Miller
HR Medic
VE Medic
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

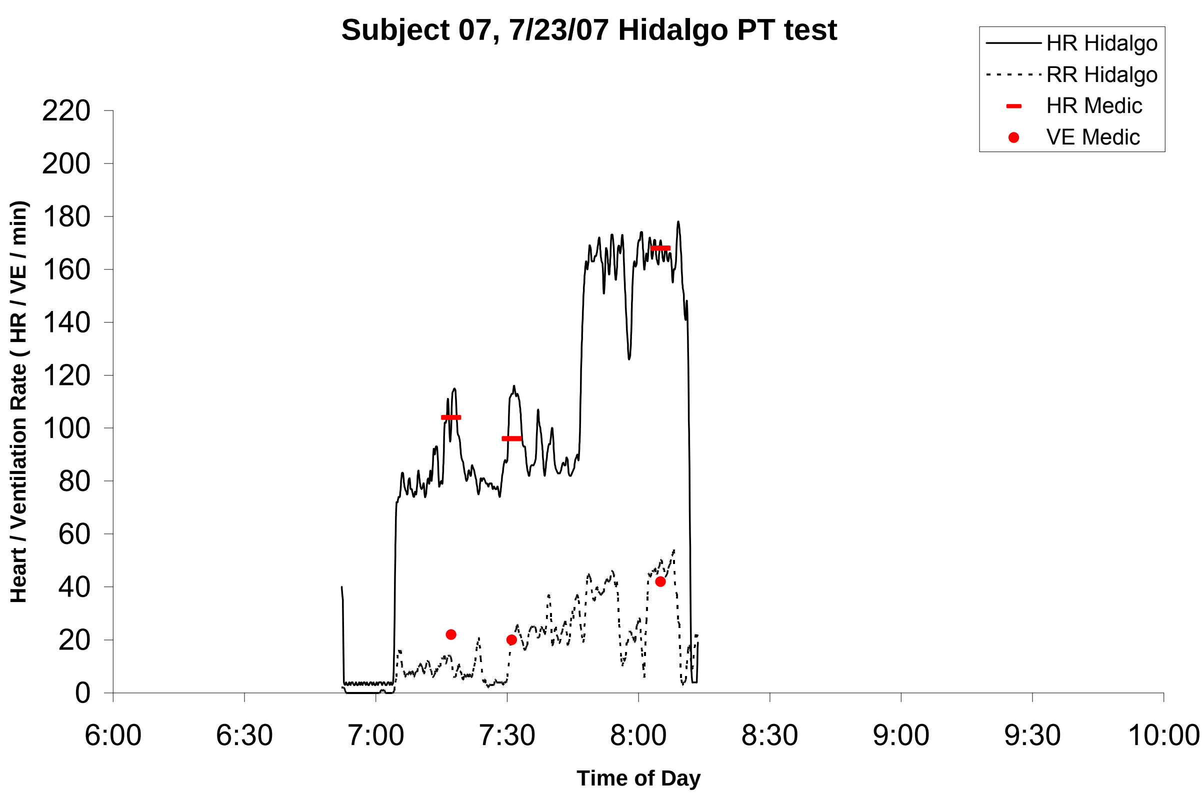


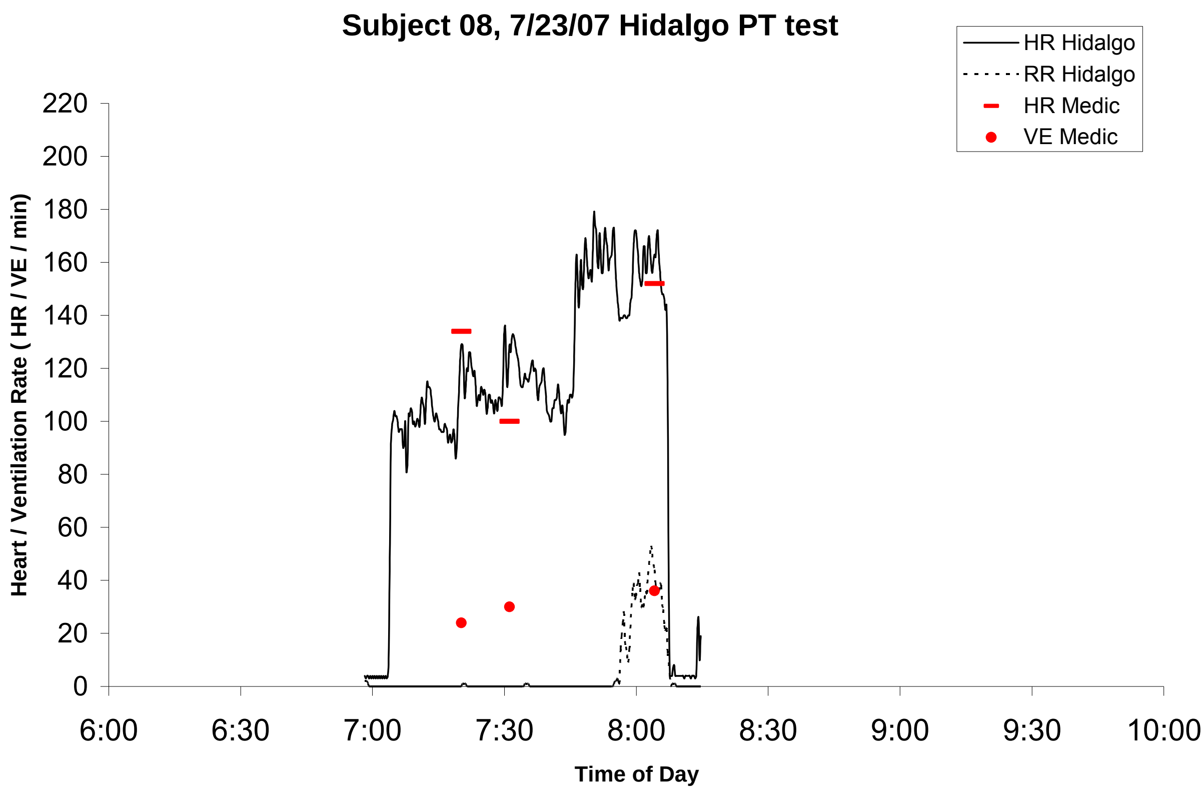
Subject 03, 7/23/07 Foster Miller PT test
Heart / Ventilation Rate (HR / VE / min)
Time of Day
HR Foster Miller
VE Foster Miller
HR Medic
VE Medic
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

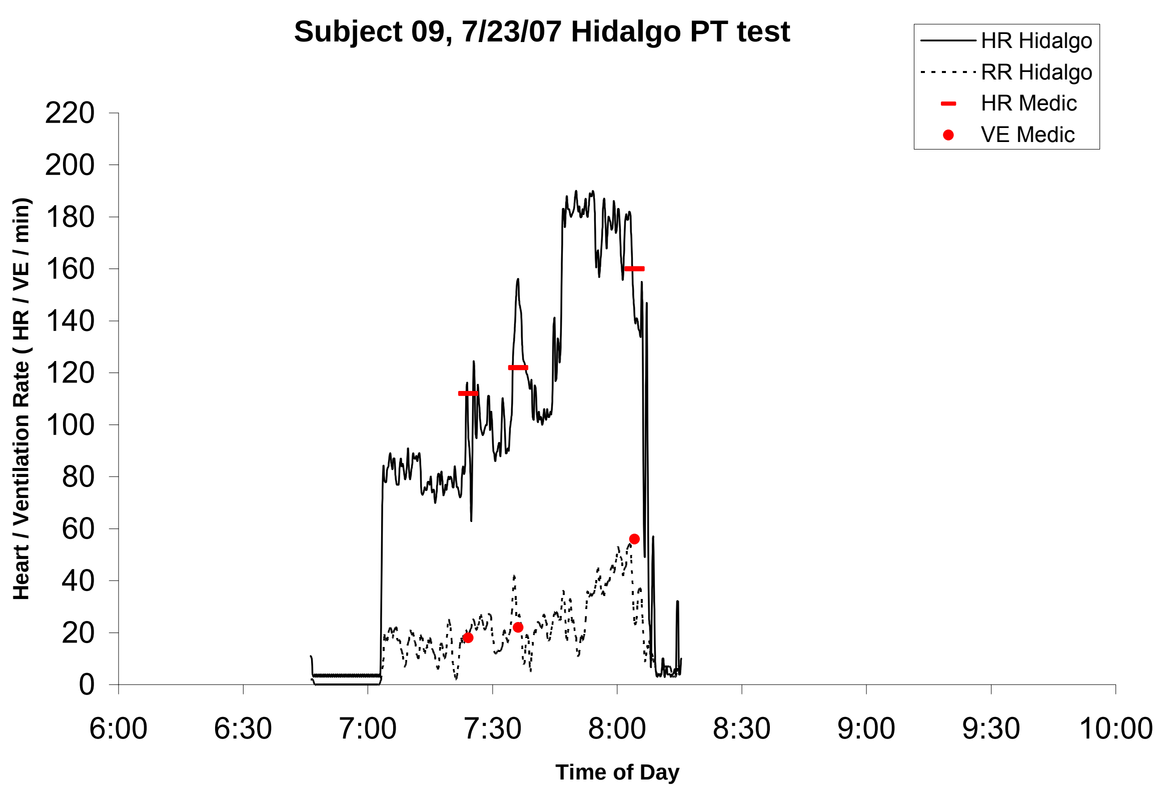

Subject 04, 7-23-07 Foster Miller PT test
HR Foster Miller
VE Foster Miller
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of day

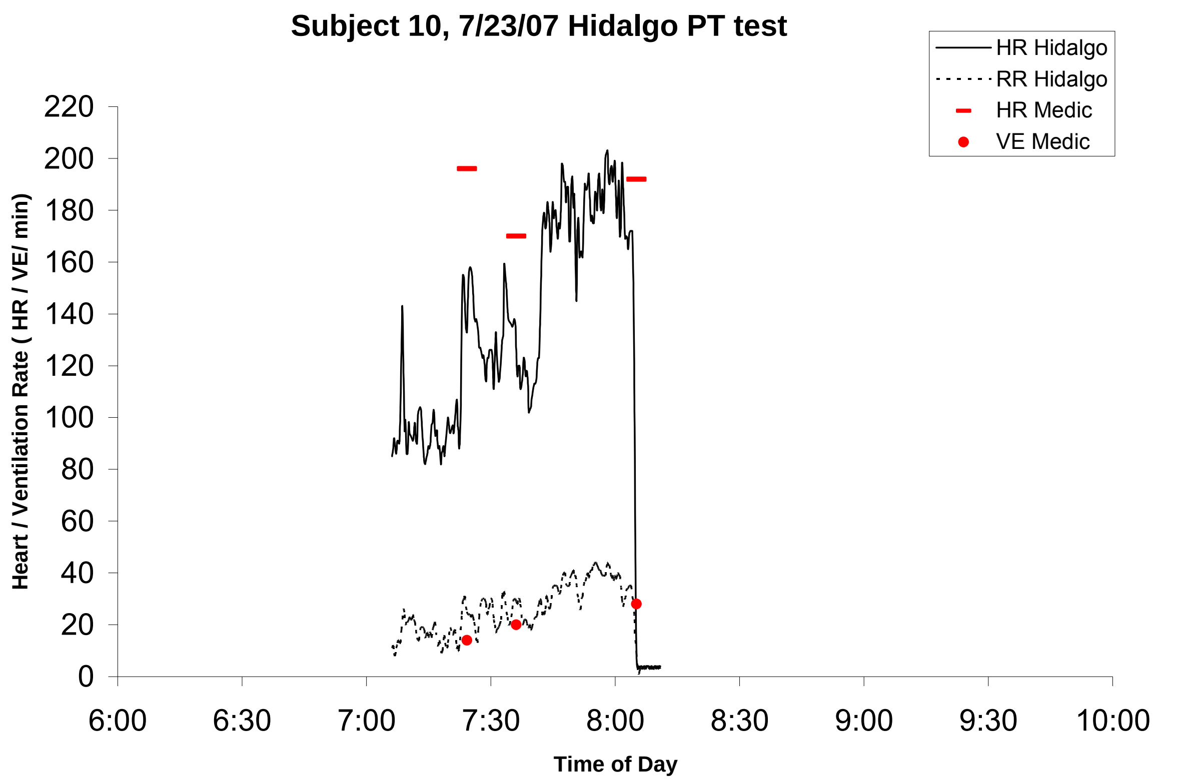

Subject 05, 7/23/07 Foster Miller PT test
HR Foster Miller
VE Foster Miller
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 06, 7/23/07 Hidalgo PT test
HR Hidalgo
VE Hidalgo
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE/ min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

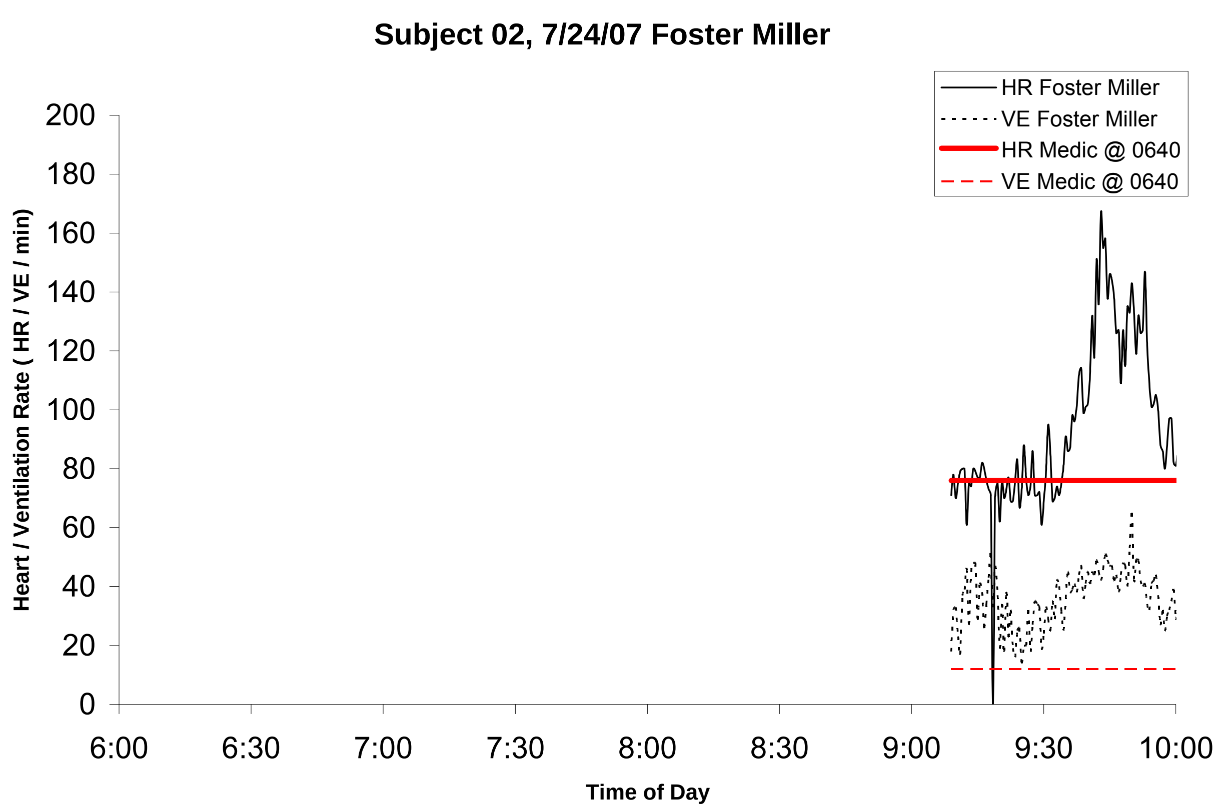

Subject 07, 7/23/07 Hidalgo PT test
HR Hidalgo
RR Hidalgo
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 08, 7/23/07 Hidalgo PT test
HR Hidalgo
RR Hidalgo
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 09, 7/23/07 Hidalgo PT test
HR Hidalgo
RR Hidalgo
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

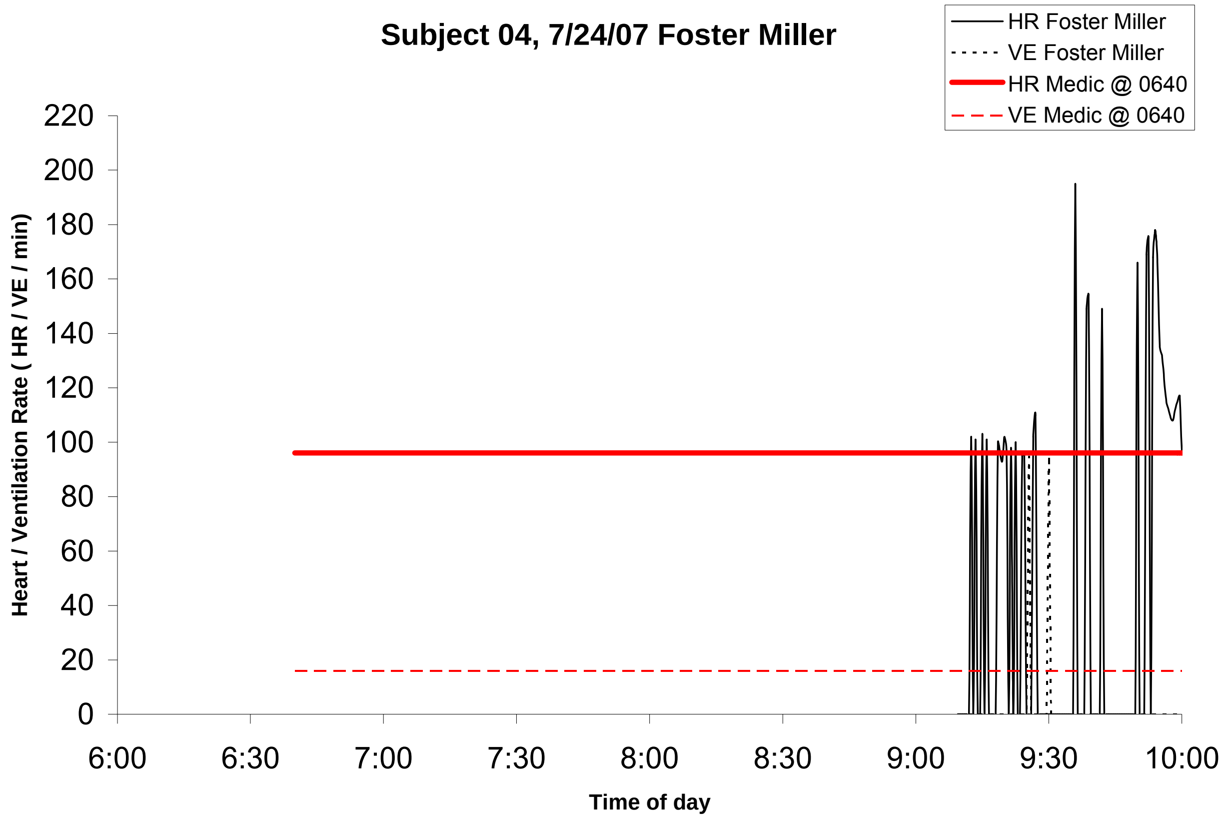


Subject 10, 7/23/07 Hidalgo PT test
HR Hidalgo
RR Hidalgo
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE/ min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

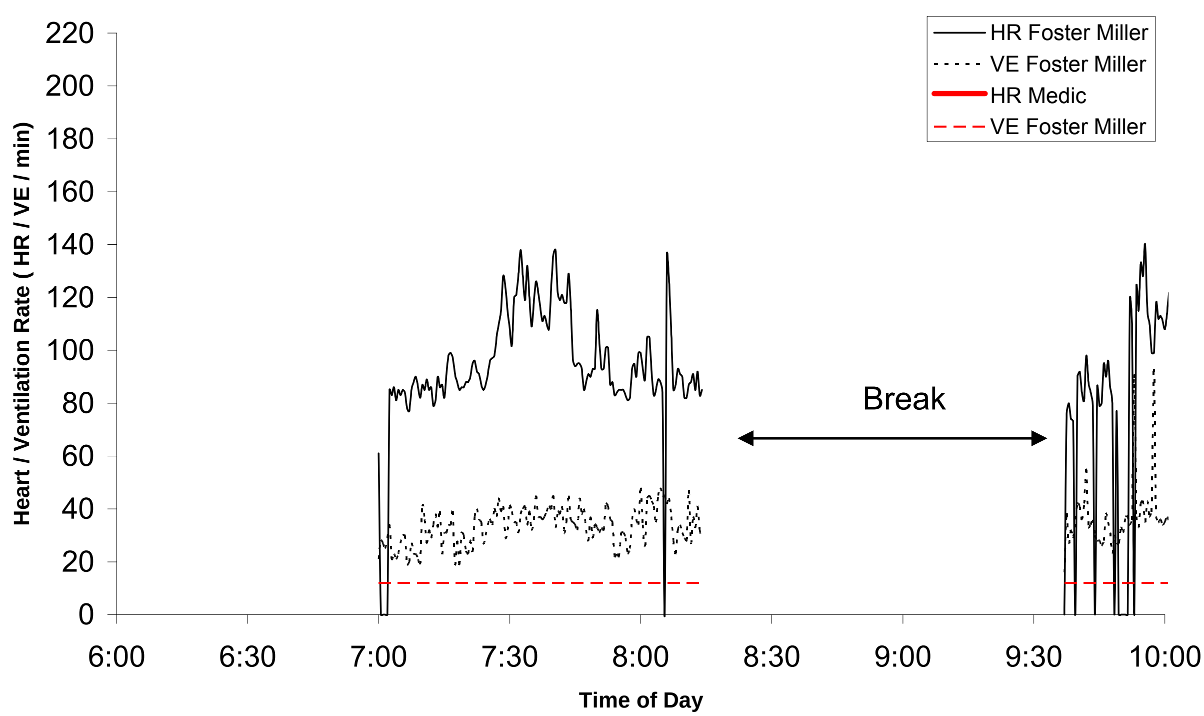


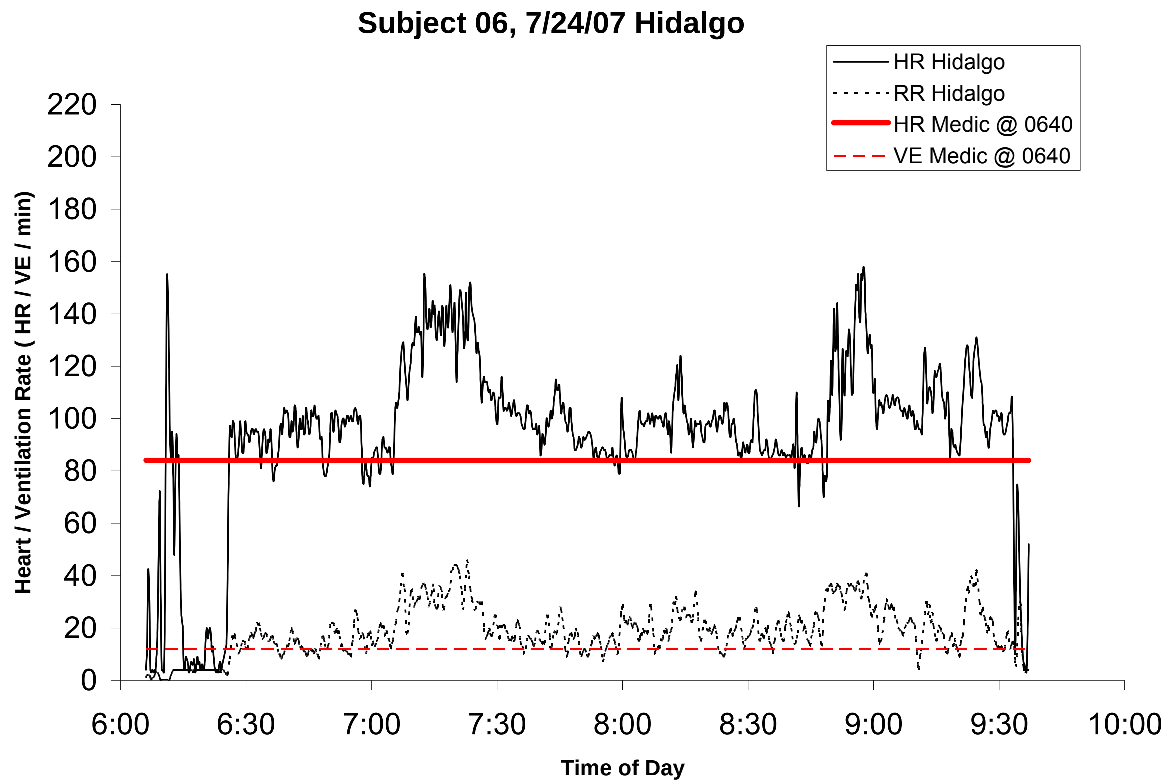
Subject 02, 7/24/07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Medic @ 0640
VE Medic @ 0640
Heart / Ventilation Rate (HR / VE / min)
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

Subject 04, 7/24/07 Foster Miller

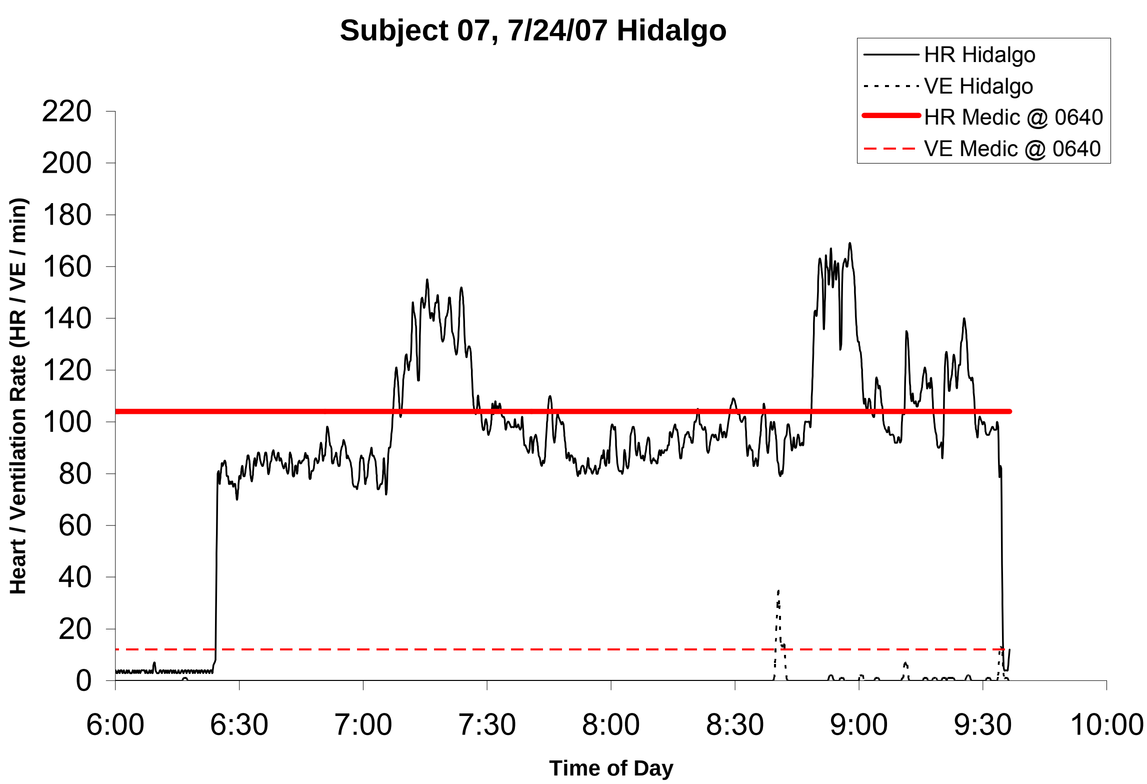


Subject 05, 7/24/07 Foster Miller

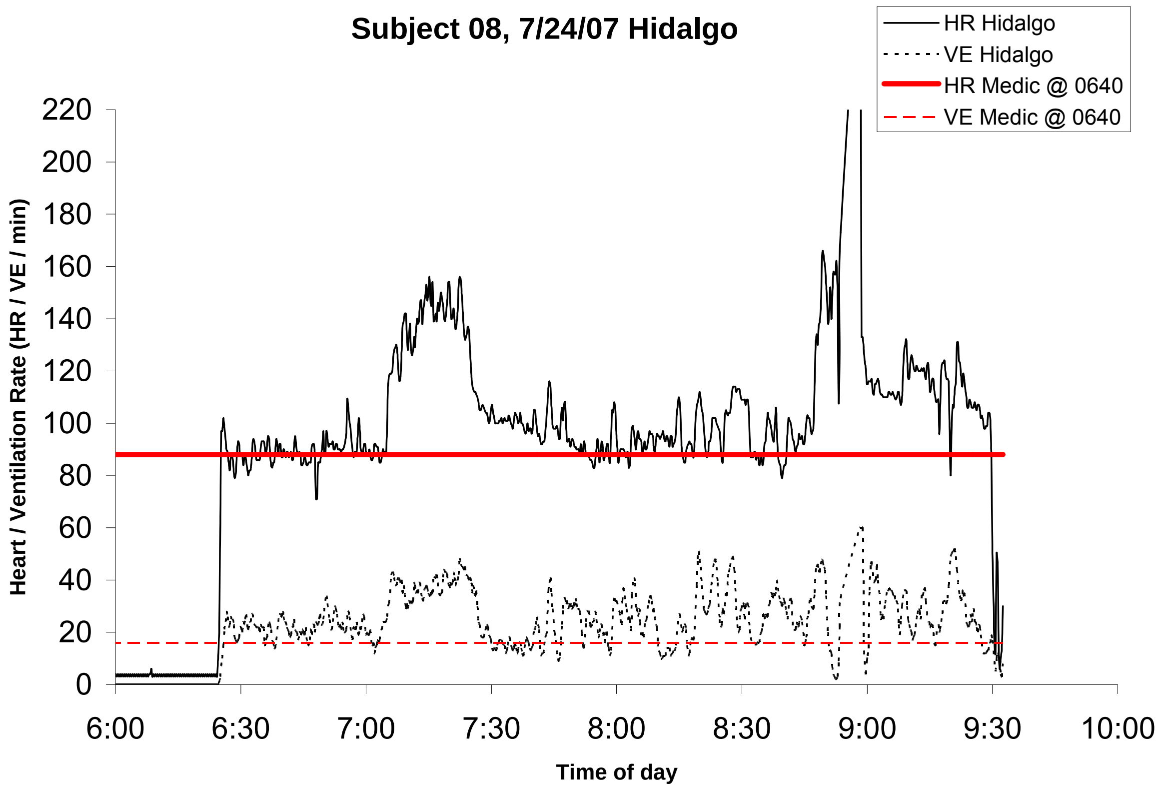


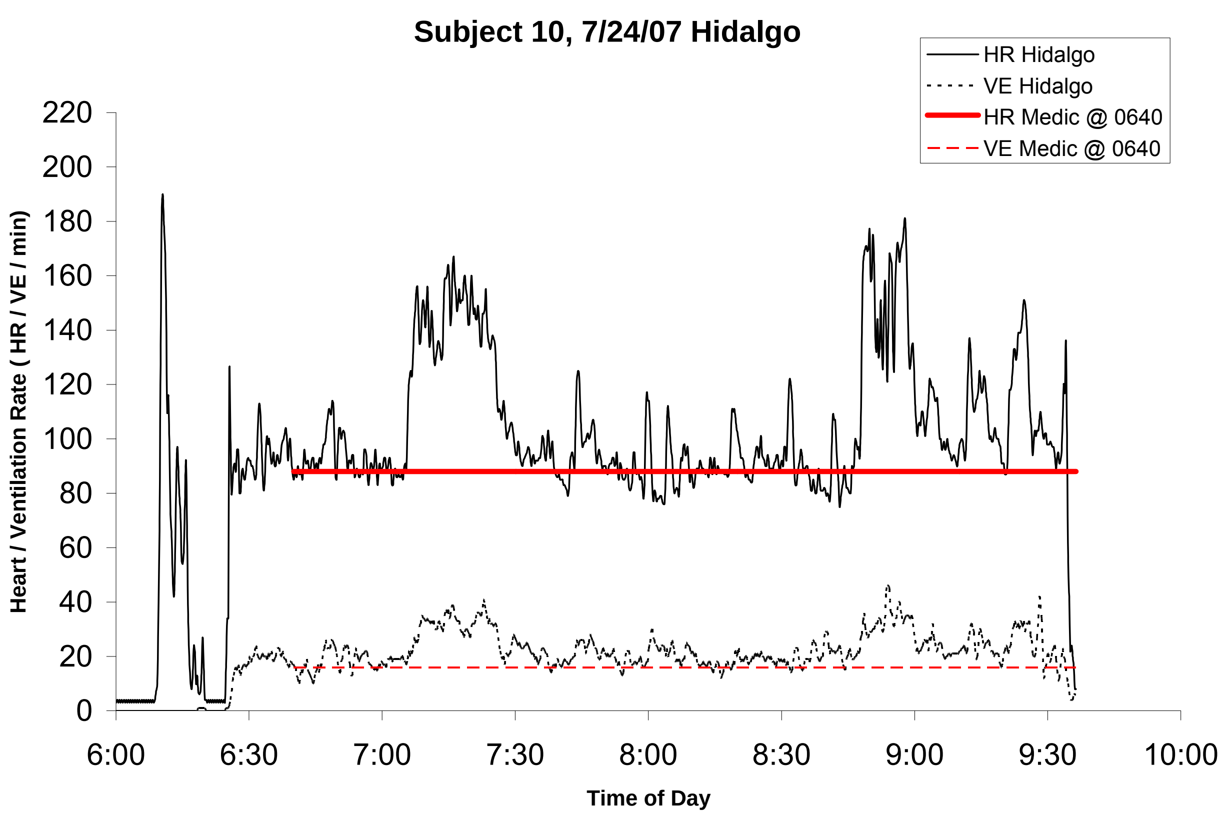


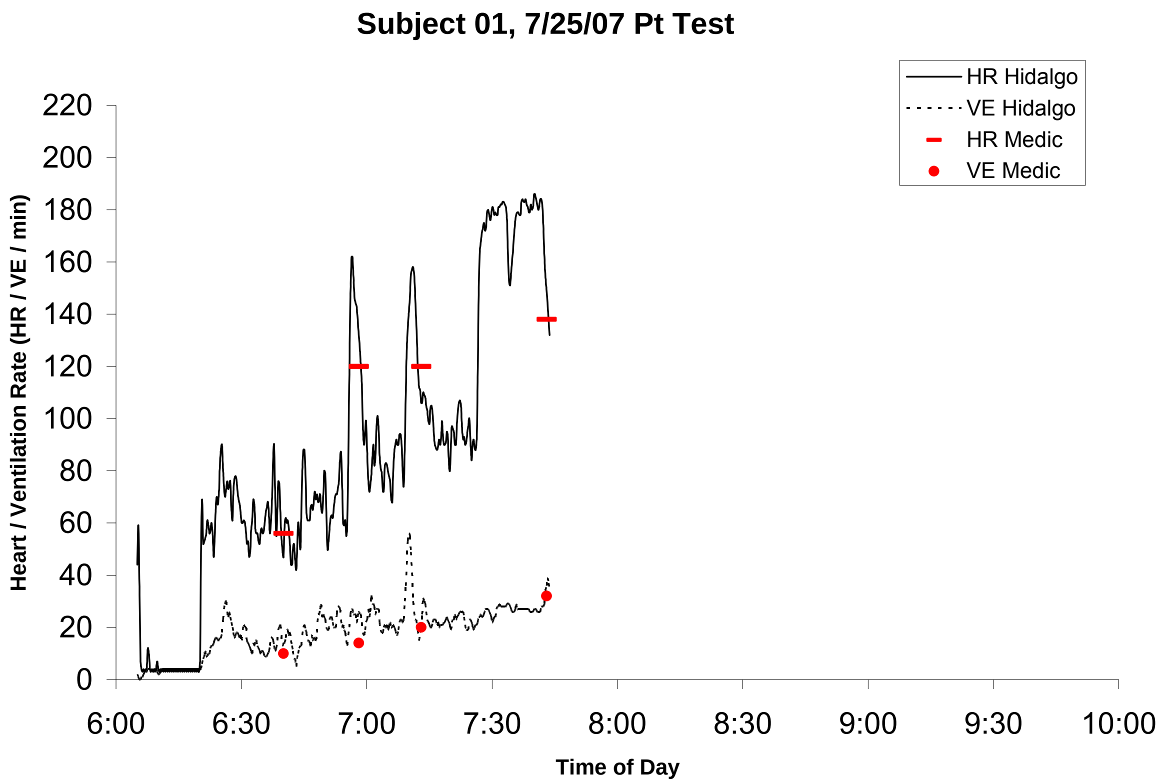
Subject 06, 7/24/07 Hidalgo
HR Hidalgo
RR Hidalgo
HR Medic @ 0640
VE Medic @ 0640
220
200
180
160
140
120
100
80
60
40
20
0
Heart / Ventilation Rate (HR / VE / min)
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day



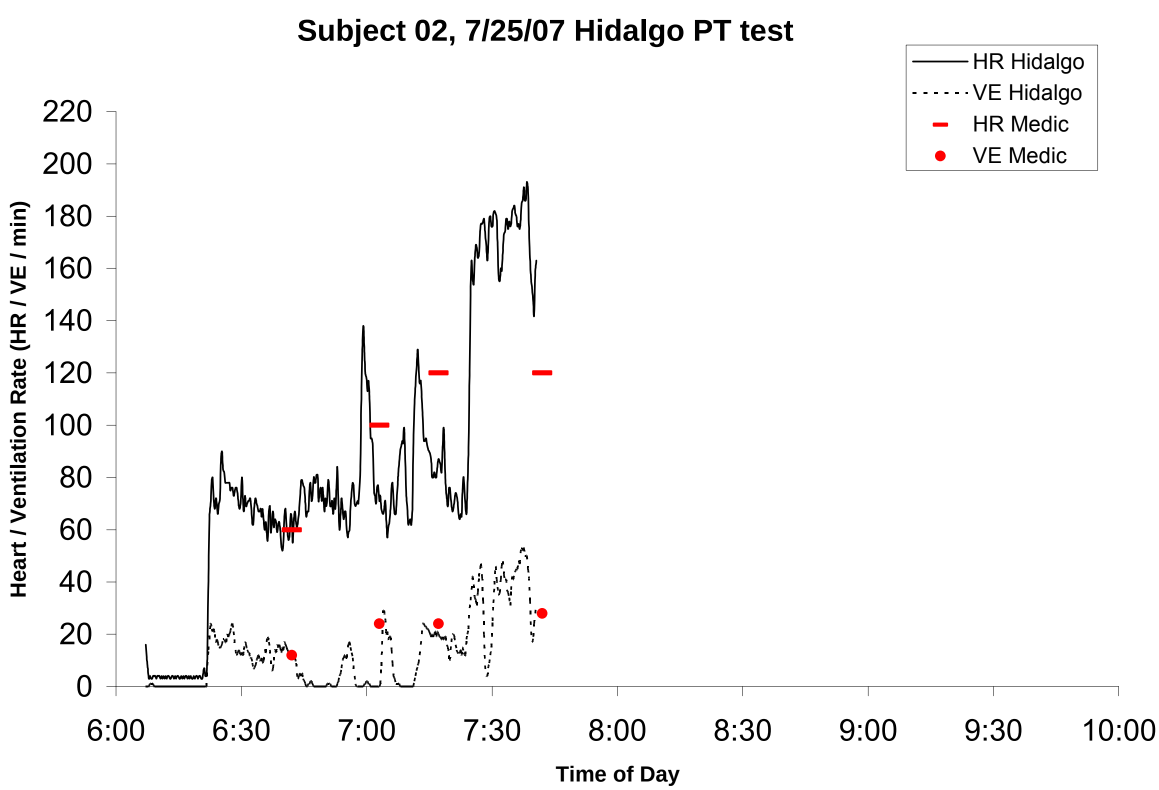
Subject 07, 7/24/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0640
VE Medic @ 0640
220
200
180
160
140
120
100
80
60
40
20
0
Heart / Ventilation Rate (HR / VE / min)
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 08, 7/24/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0640
VE Medic @ 0640
Heart / Ventilation Rate (HR / VE / min)
Time of day
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

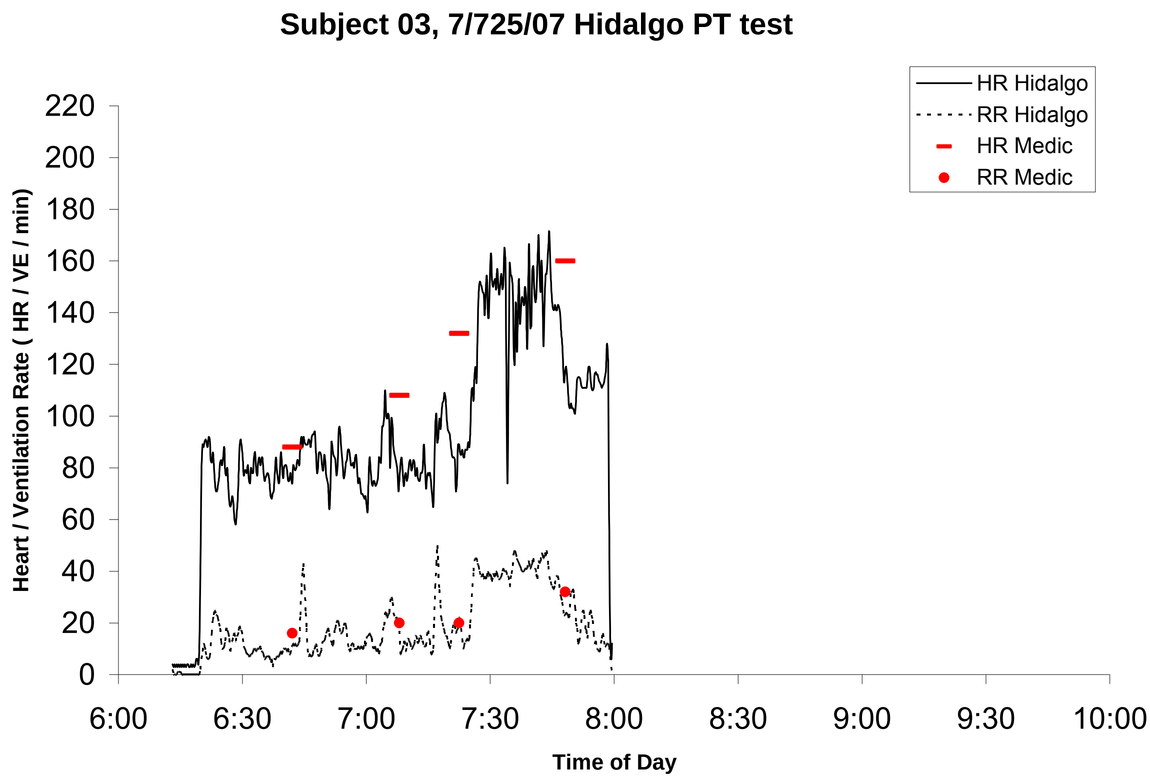

Subject 10, 7/24/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0640
VE Medic @ 0640
Heart / Ventilation Rate (HR / VE / min)
Time of Day
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

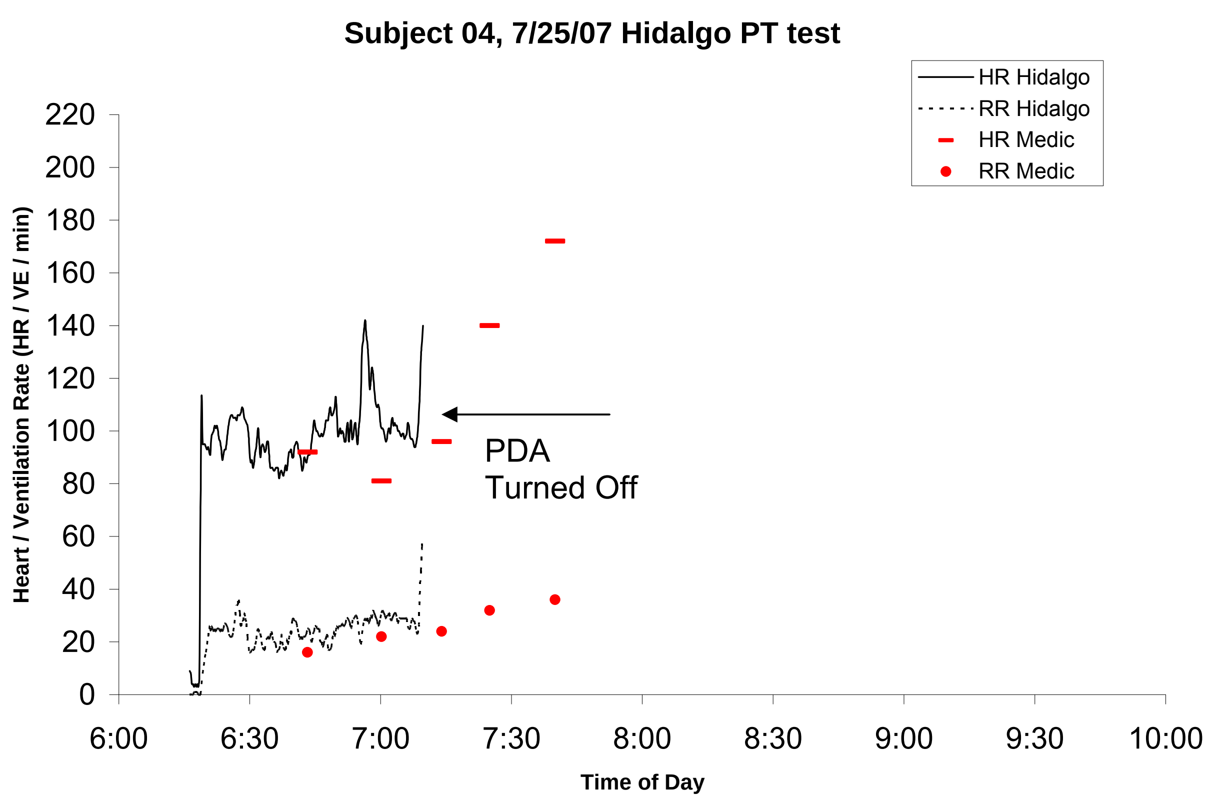


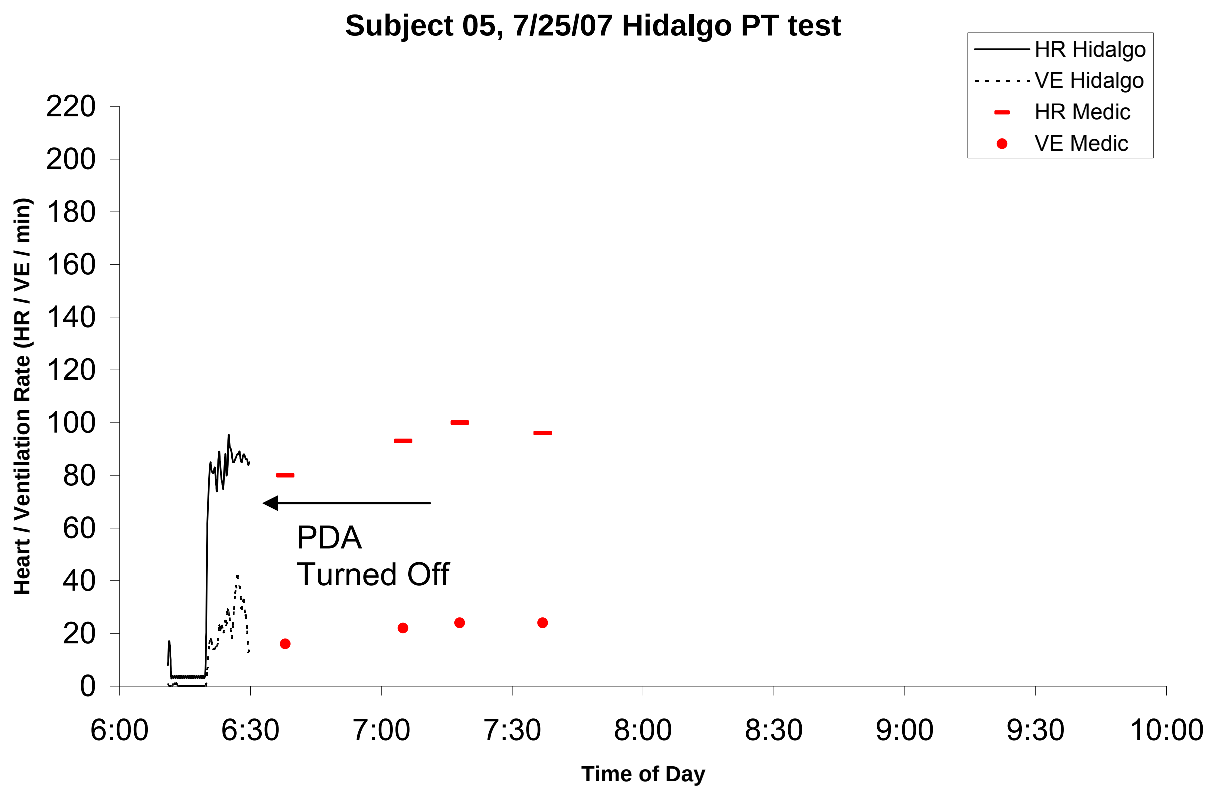
Subject 01, 7/25/07 Pt Test
HR Hidalgo
VE Hidalgo
HR Medic
VE Medic
220
200
180
160
140
120
100
80
60
40
20
0
Heart / Ventilation Rate (HR / VE / min)
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

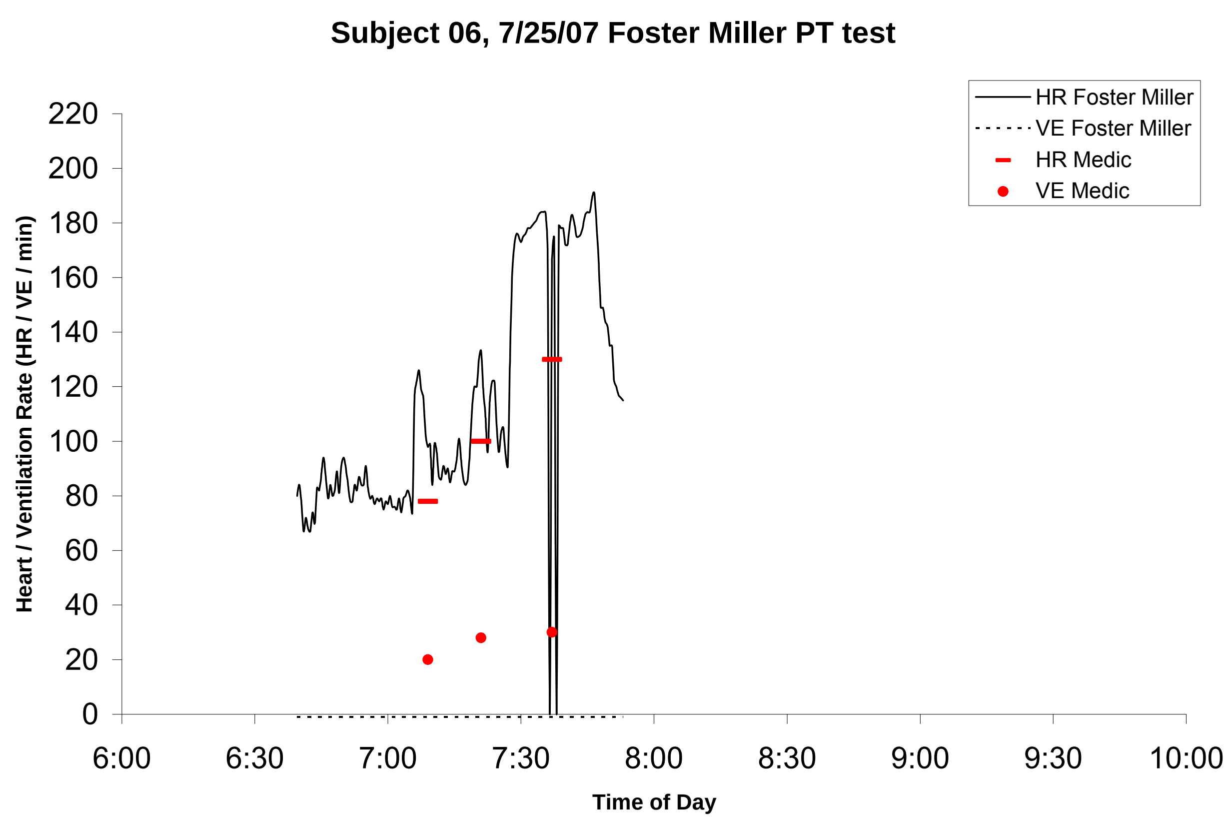


Subject 02, 7/25/07 Hidalgo PT test
HR Hidalgo
VE Hidalgo
HR Medic
VE Medic
220
200
180
160
140
120
100
80
60
40
20
0
Heart / Ventilation Rate (HR / VE / min)
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

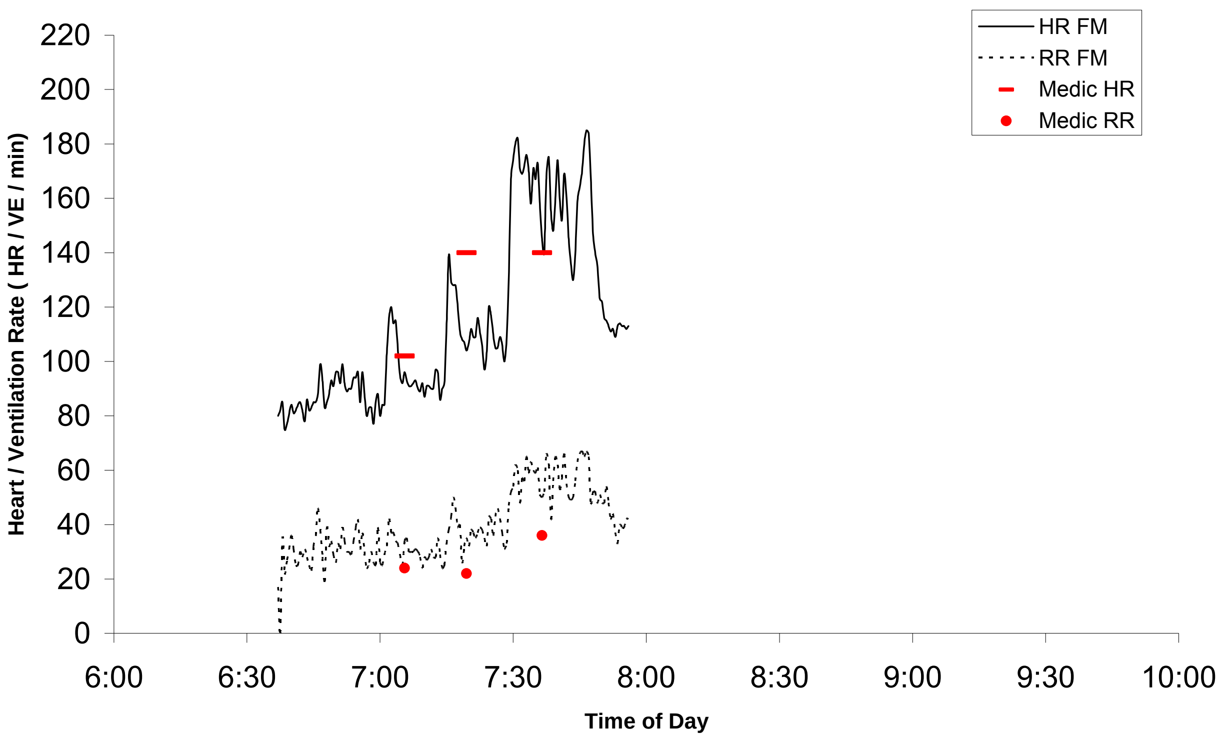

Subject 03, 7/725/07 Hidalgo PT test
HR Hidalgo
RR Hidalgo
HR Medic
RR Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 04, 7/25/07 Hidalgo PT test
HR Hidalgo
RR Hidalgo
HR Medic
RR Medic
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
PDA
Turned Off
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

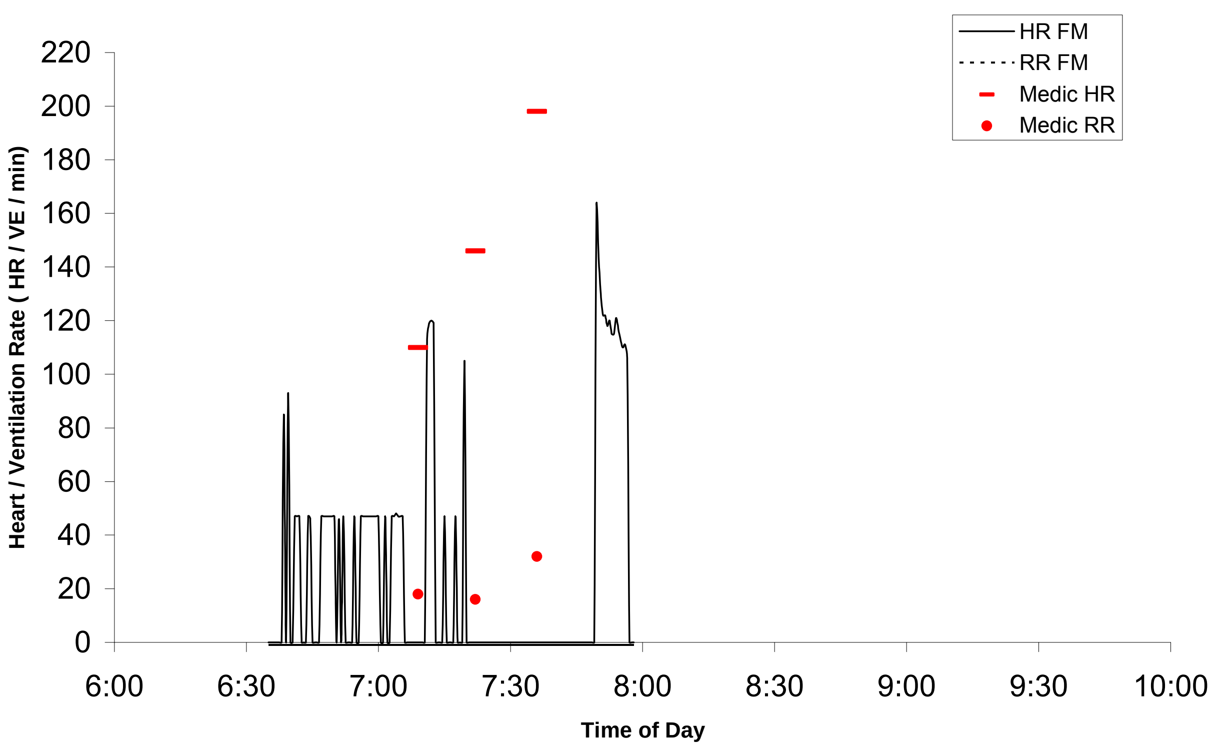

Subject 05, 7/25/07 Hidalgo PT test
HR Hidalgo
VE Hidalgo
HR Medic
VE Medic
PDA
Turned Off
Heart / Ventilation Rate (HR / VE / min)
Time of Day
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

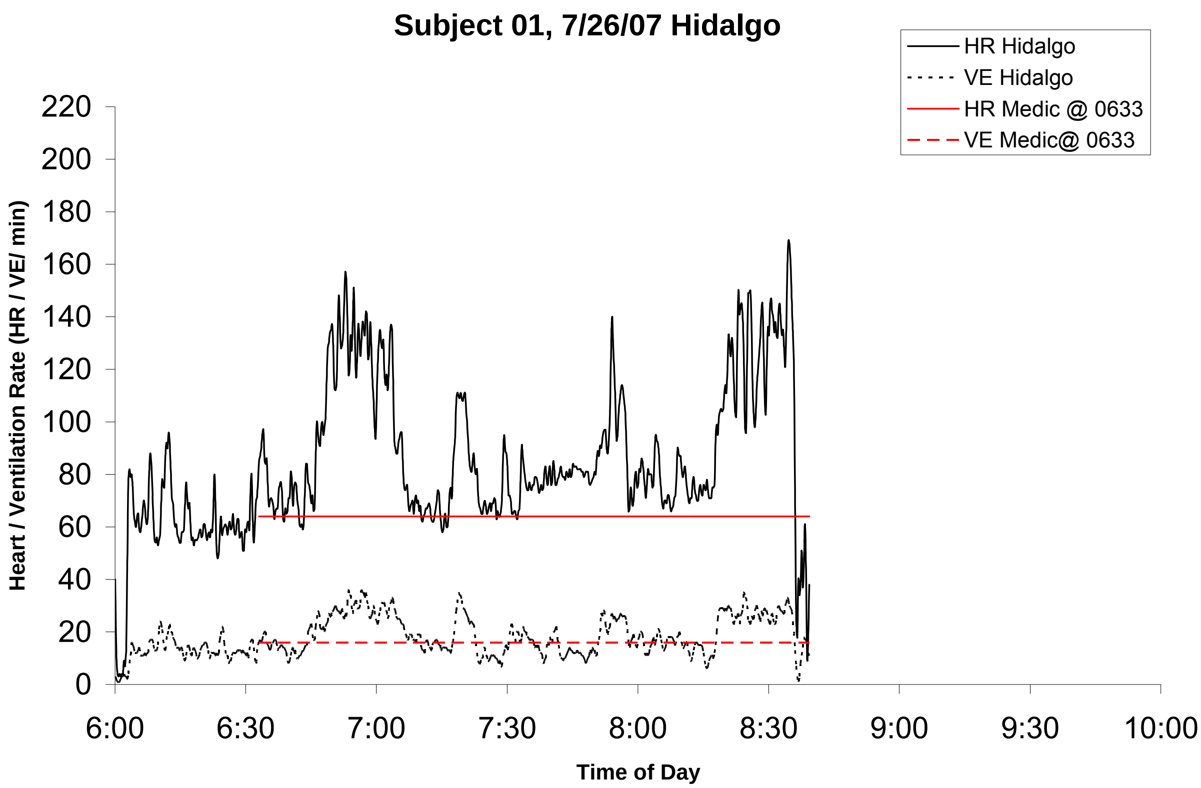

Subject 06, 7/25/07 Foster Miller PT test
HR Foster Miller
VE Foster Miller
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
Time of Day
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00

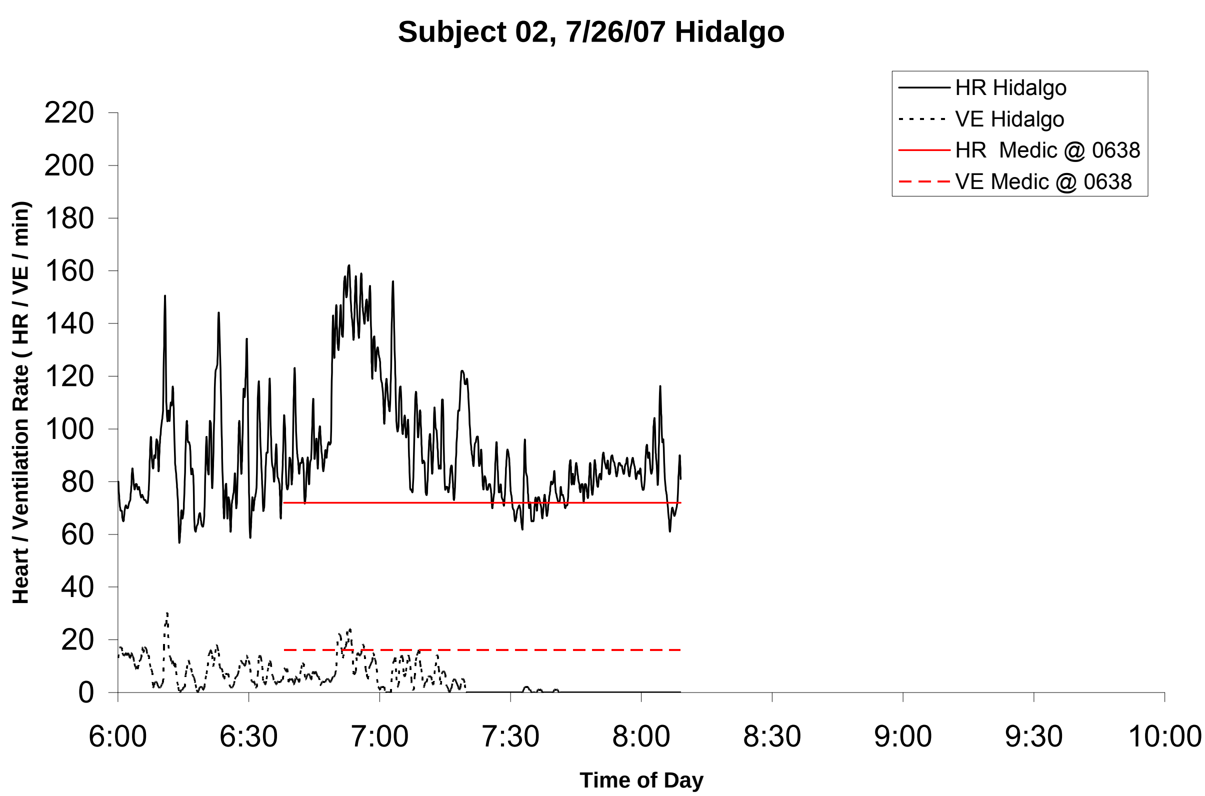
Subject 08, 7-25-07 Foster Miller PT test

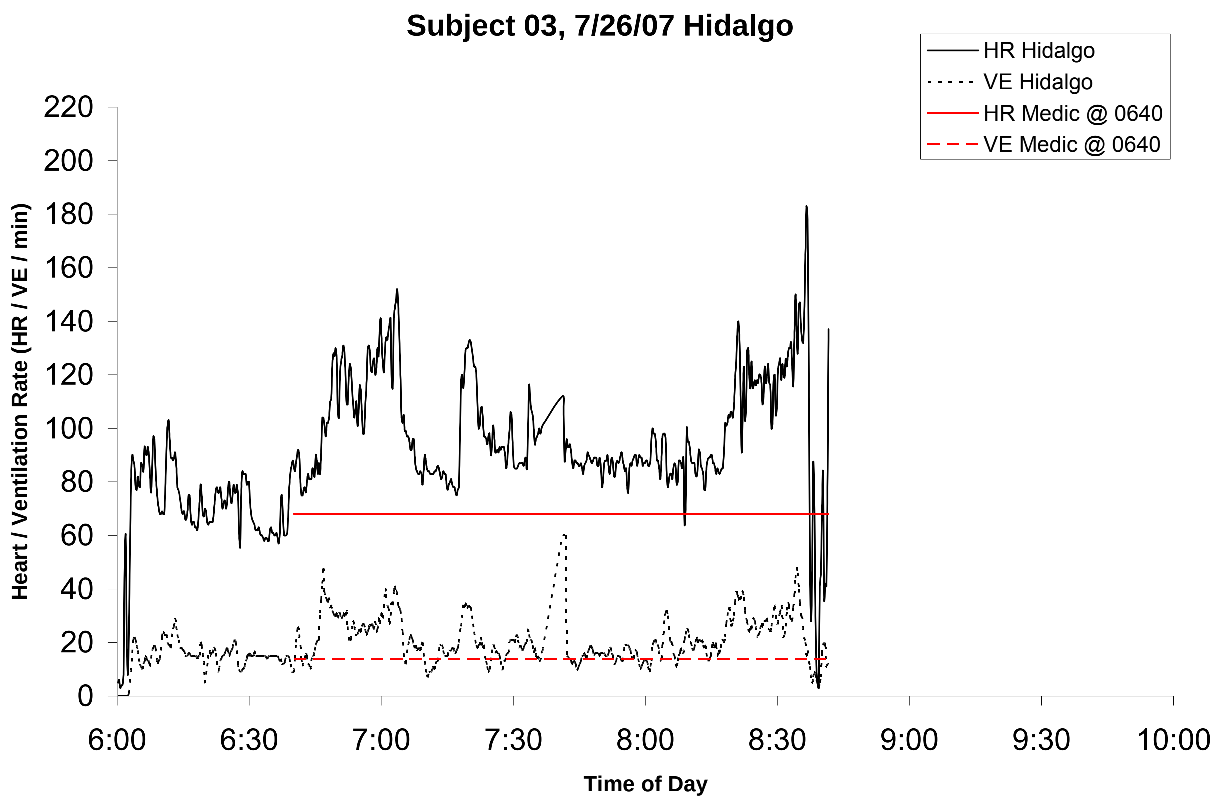


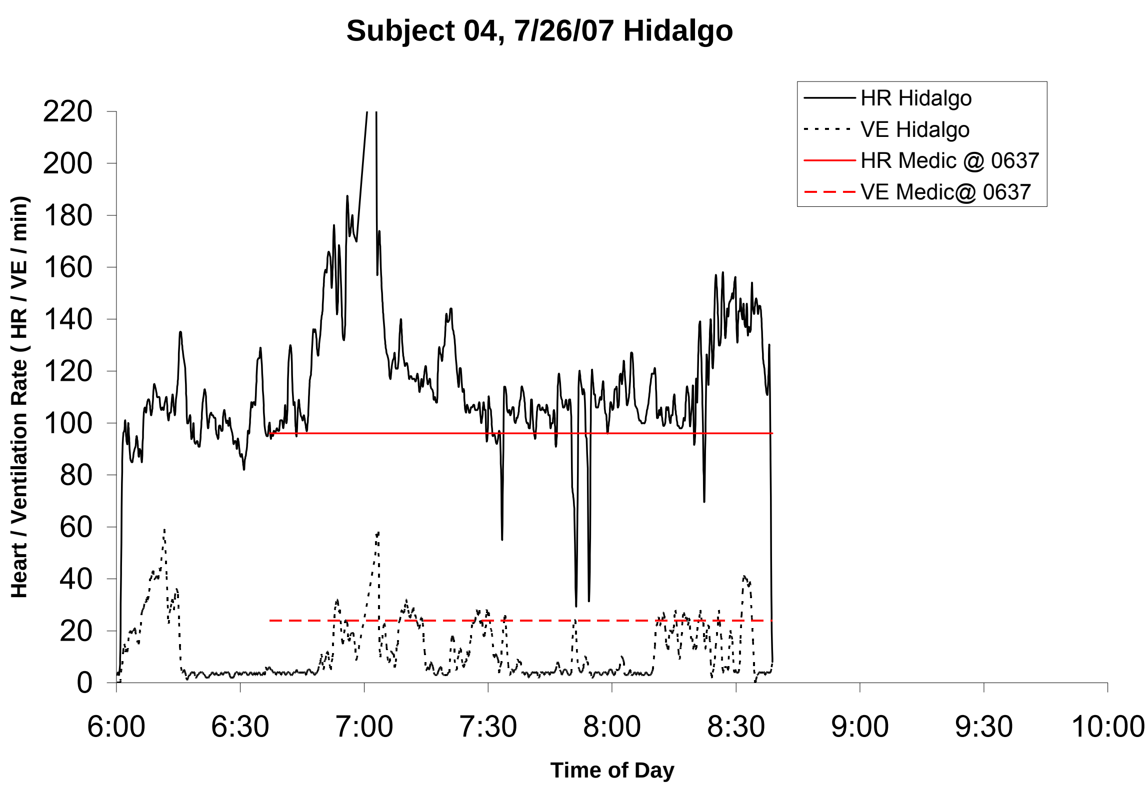
Subject 10, 7-25-07 Foster Miller PT test



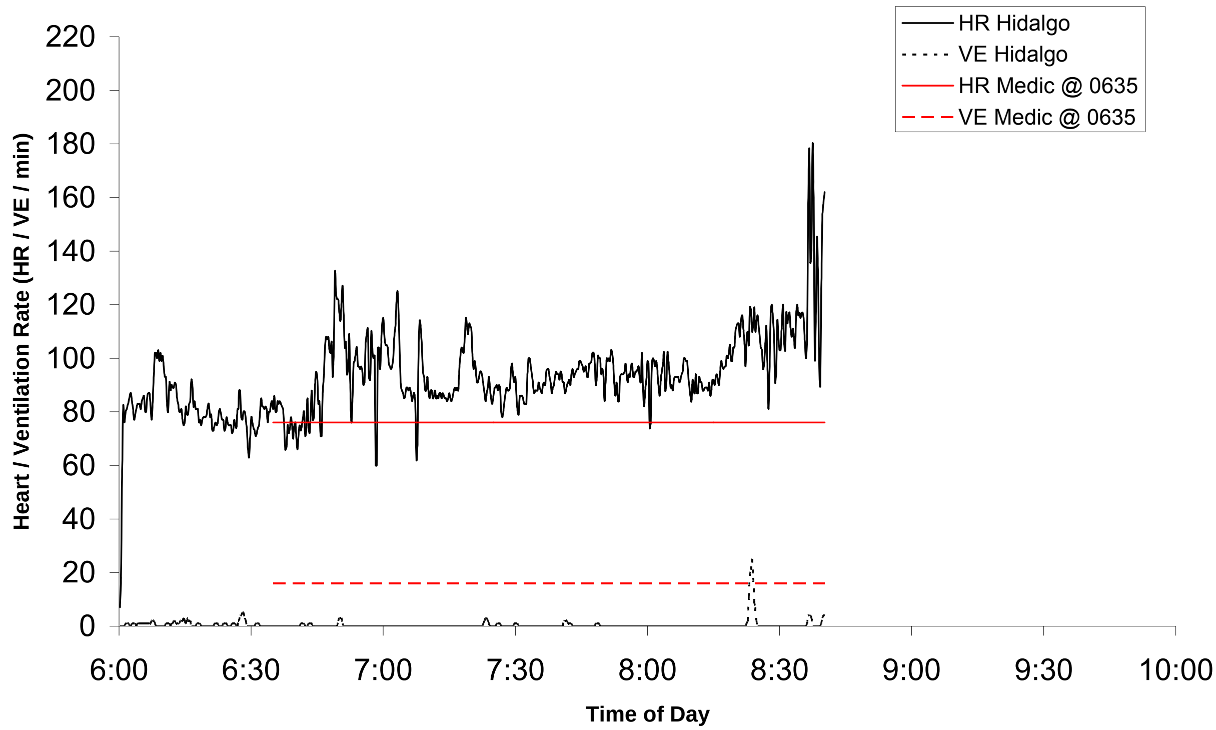

Subject 01, 7/26/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0633
VE Medic@ 0633
Heart / Ventilation Rate (HR / VE/ min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 02, 7/26/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0638
VE Medic @ 0638
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

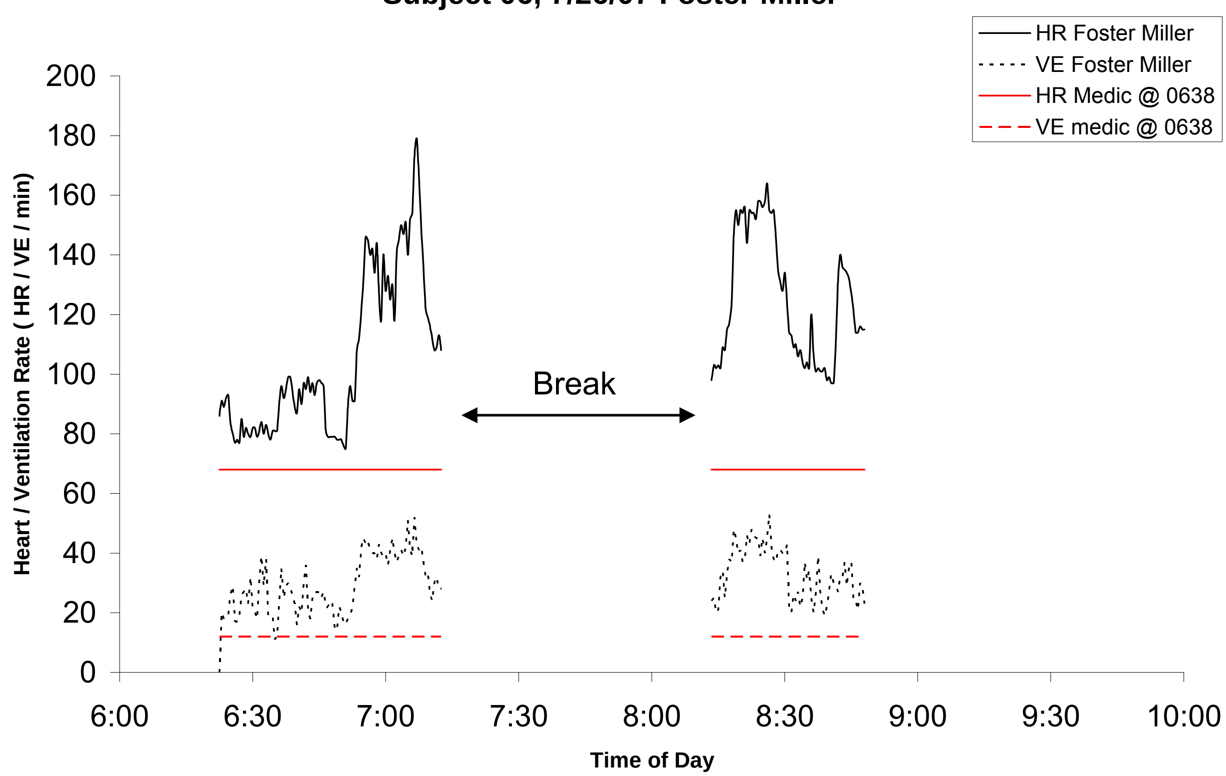

Subject 03, 7/26/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0640
VE Medic @ 0640
Heart / Ventilation Rate (HR / VE / min)
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

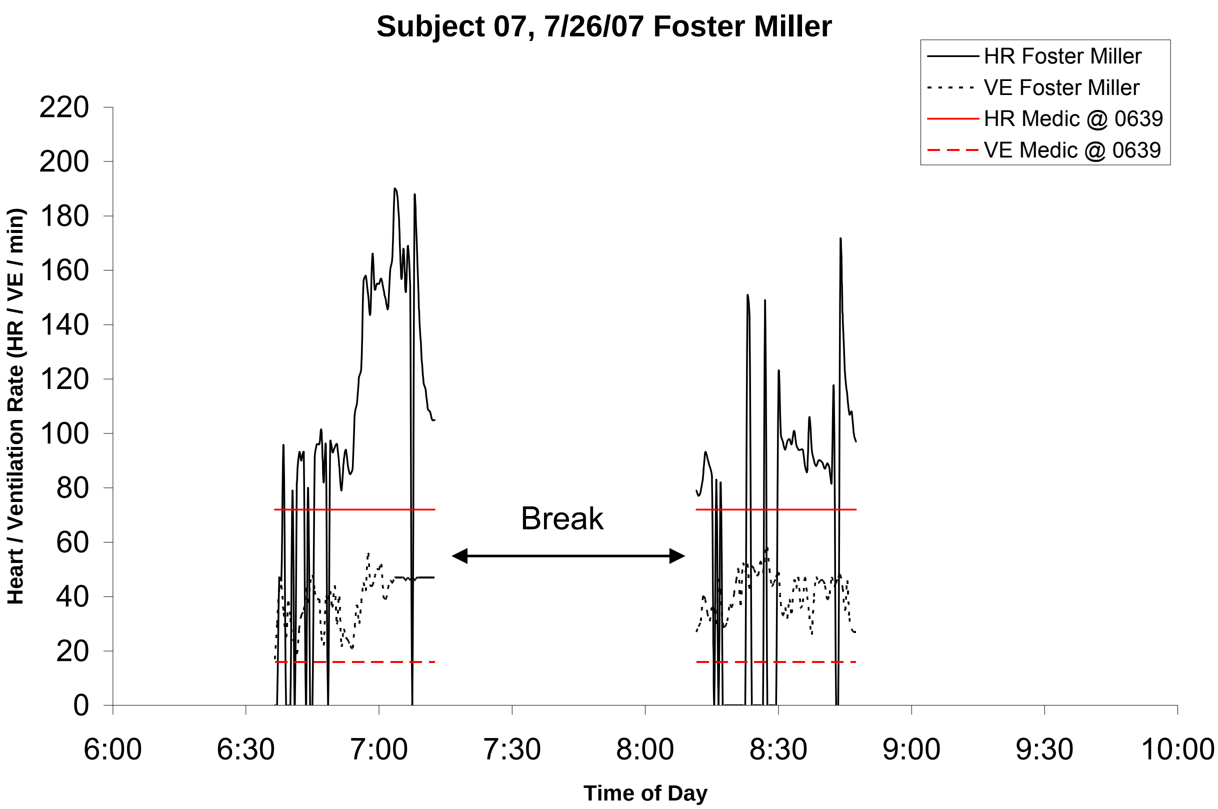

Subject 04, 7/26/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0637
VE Medic@ 0637
Heart / Ventilation Rate (HR / VE / min)
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

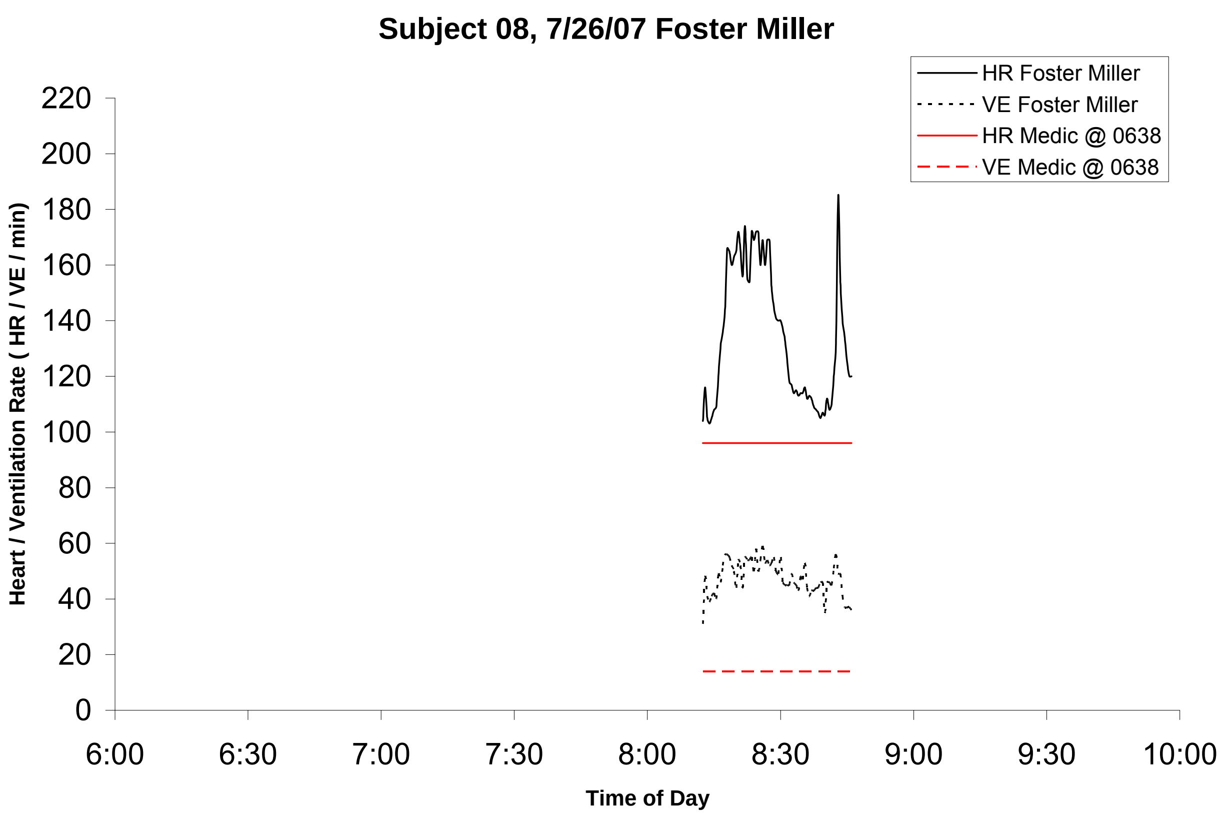
Subject 05, 7/26/07 Hidalgo



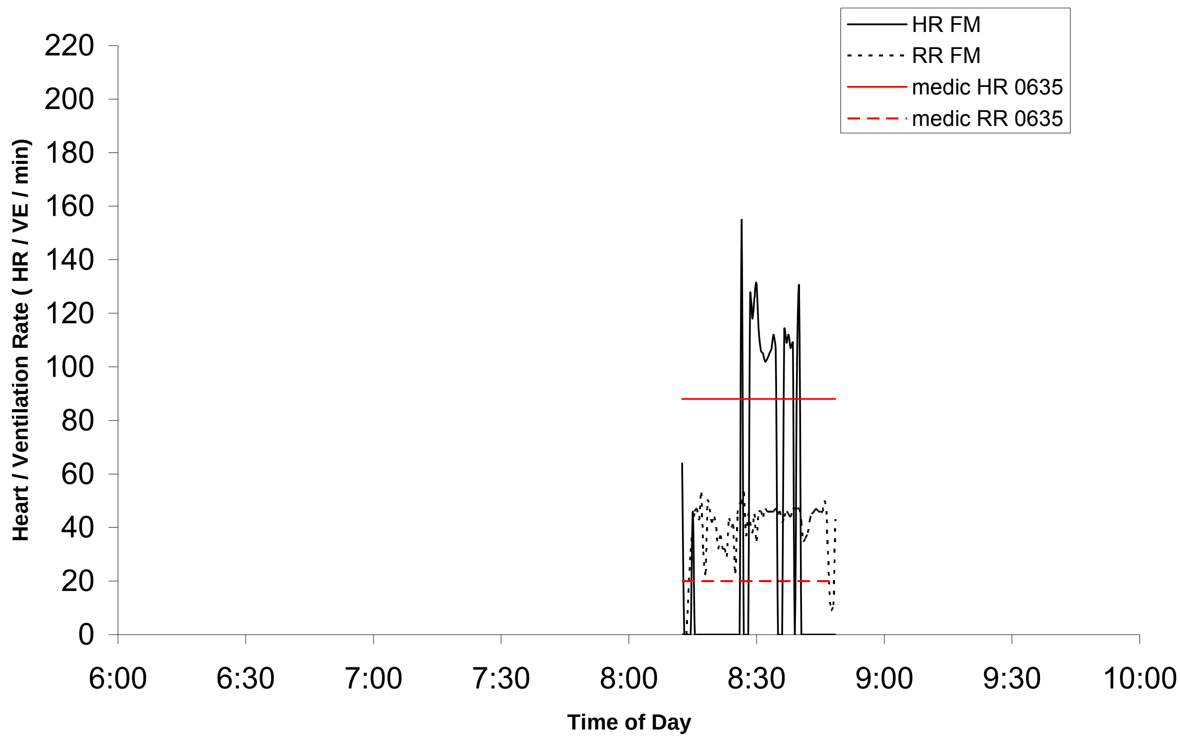
Subject 06, 7/26/07 Foster Miller



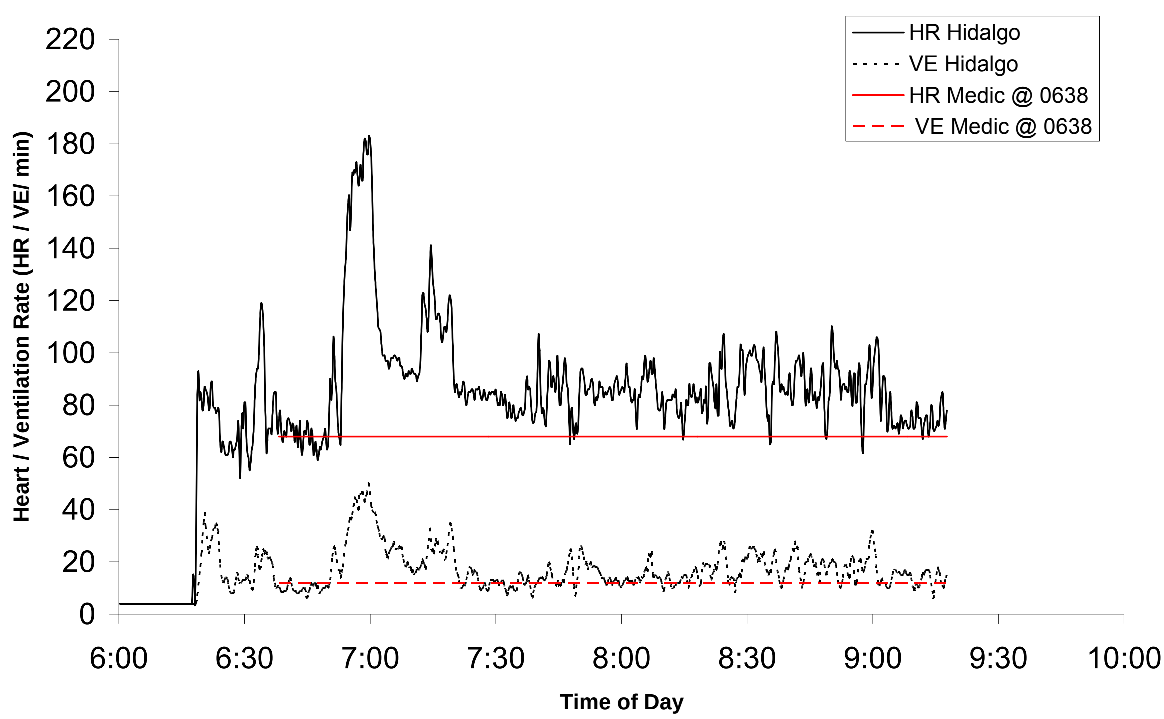

Subject 07, 7/26/07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Medic @ 0639
VE Medic @ 0639
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
Break
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

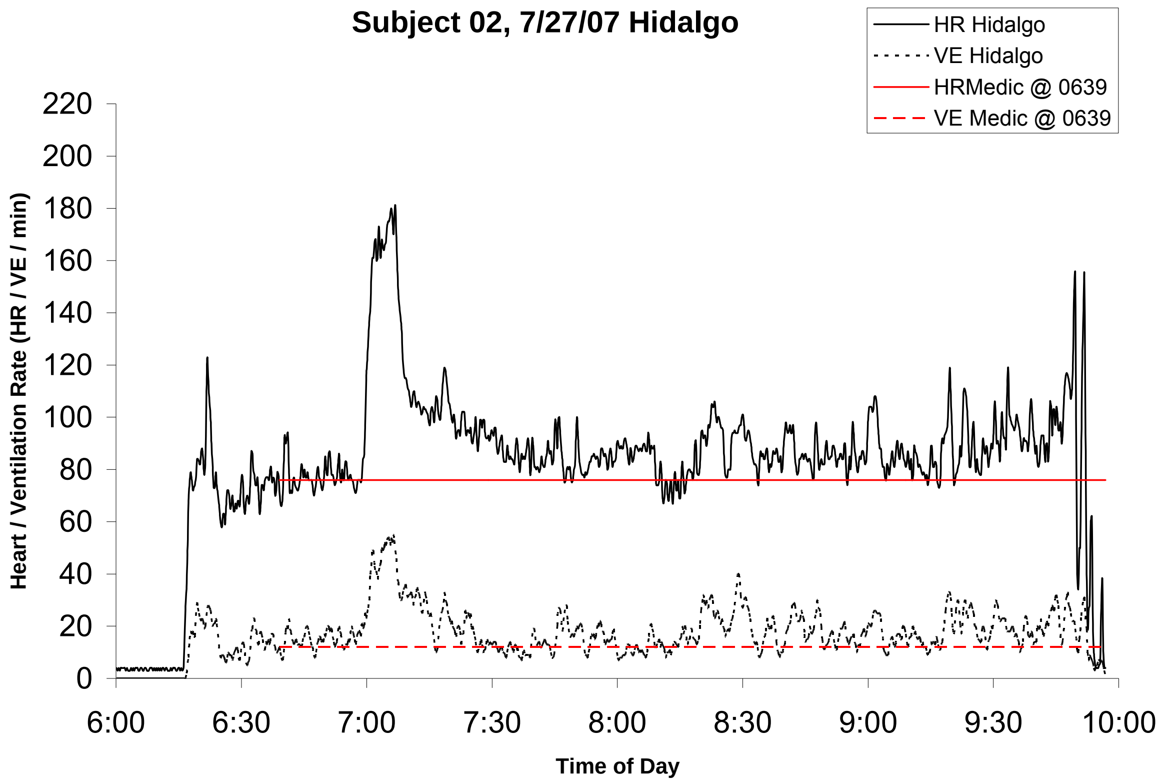

Subject 08, 7/26/07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Medic @ 0638
VE Medic @ 0638
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

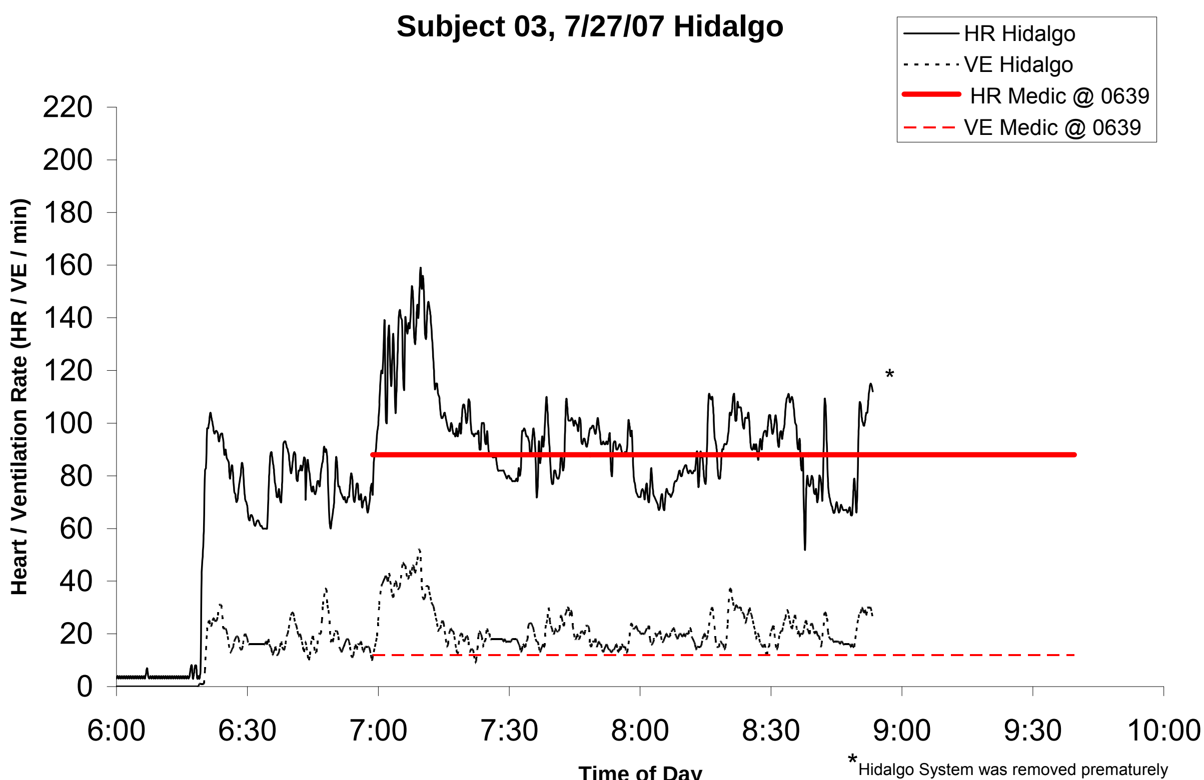
Subject 10, 7/26/07 Foster Miller



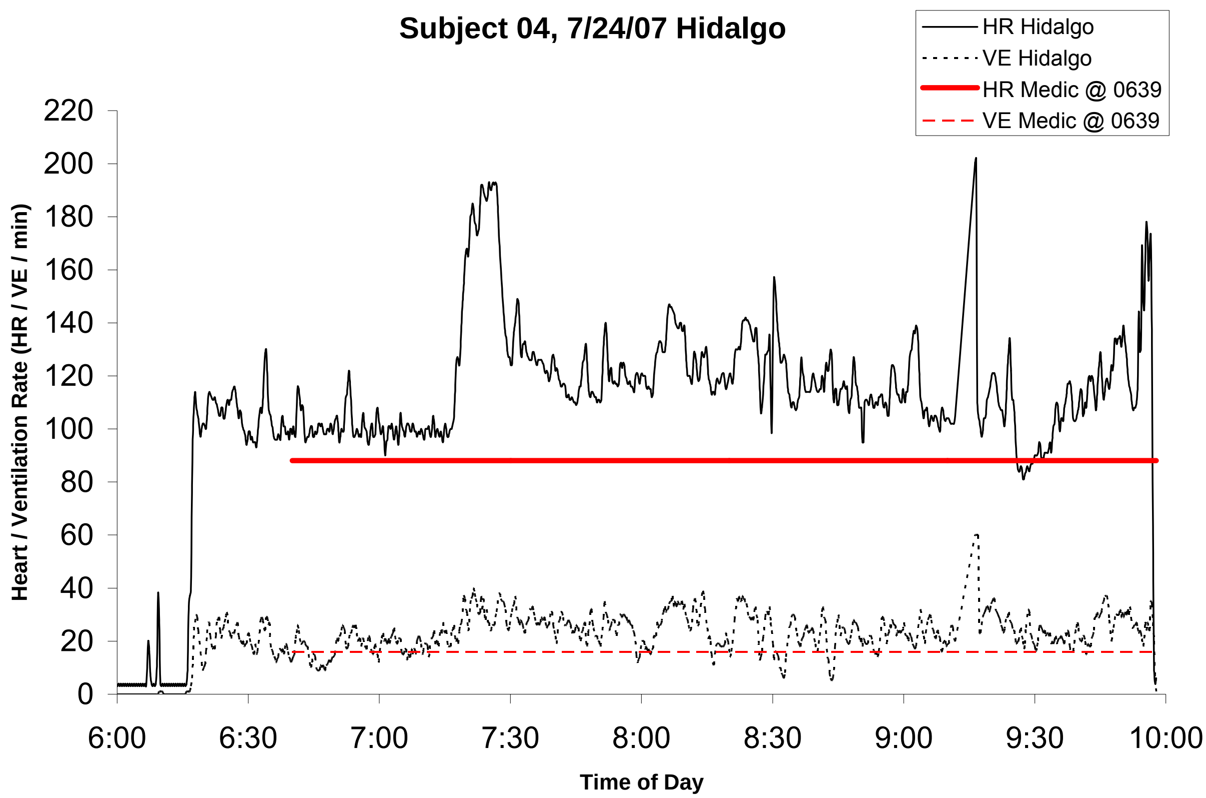
Subject 01, 7/27/07 Hidalgo



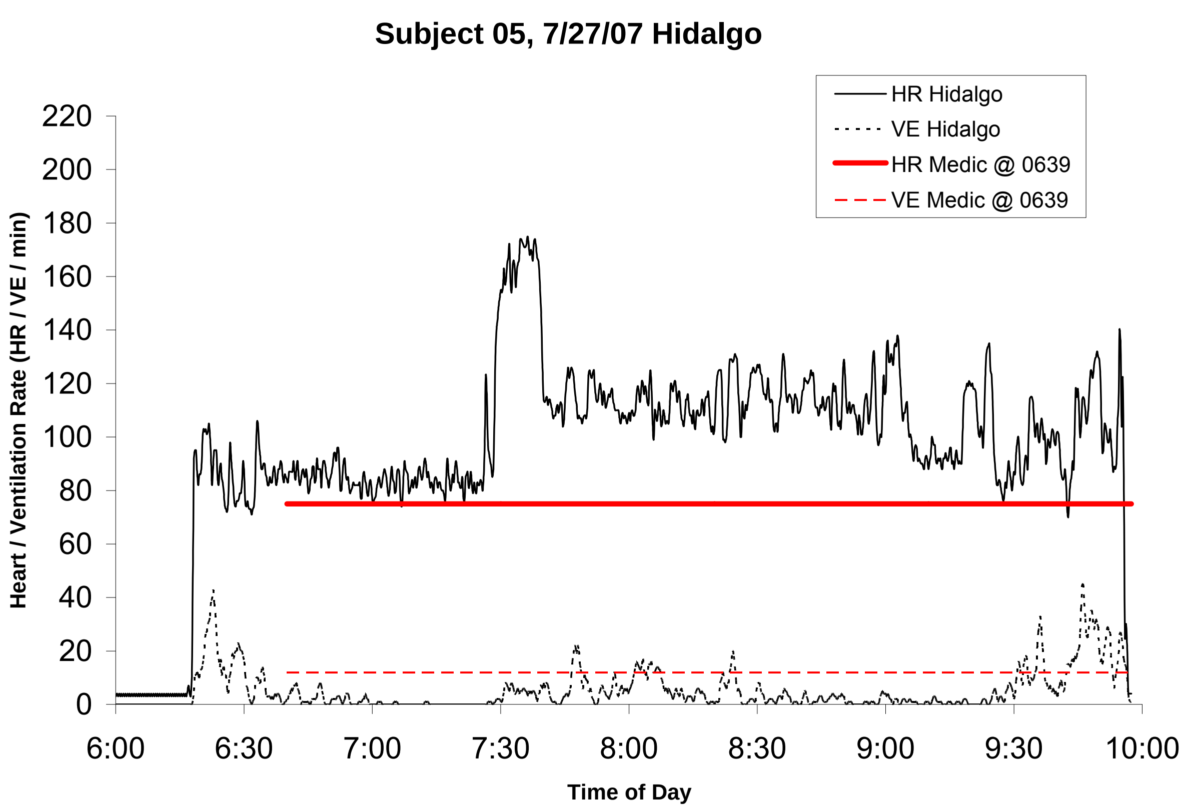




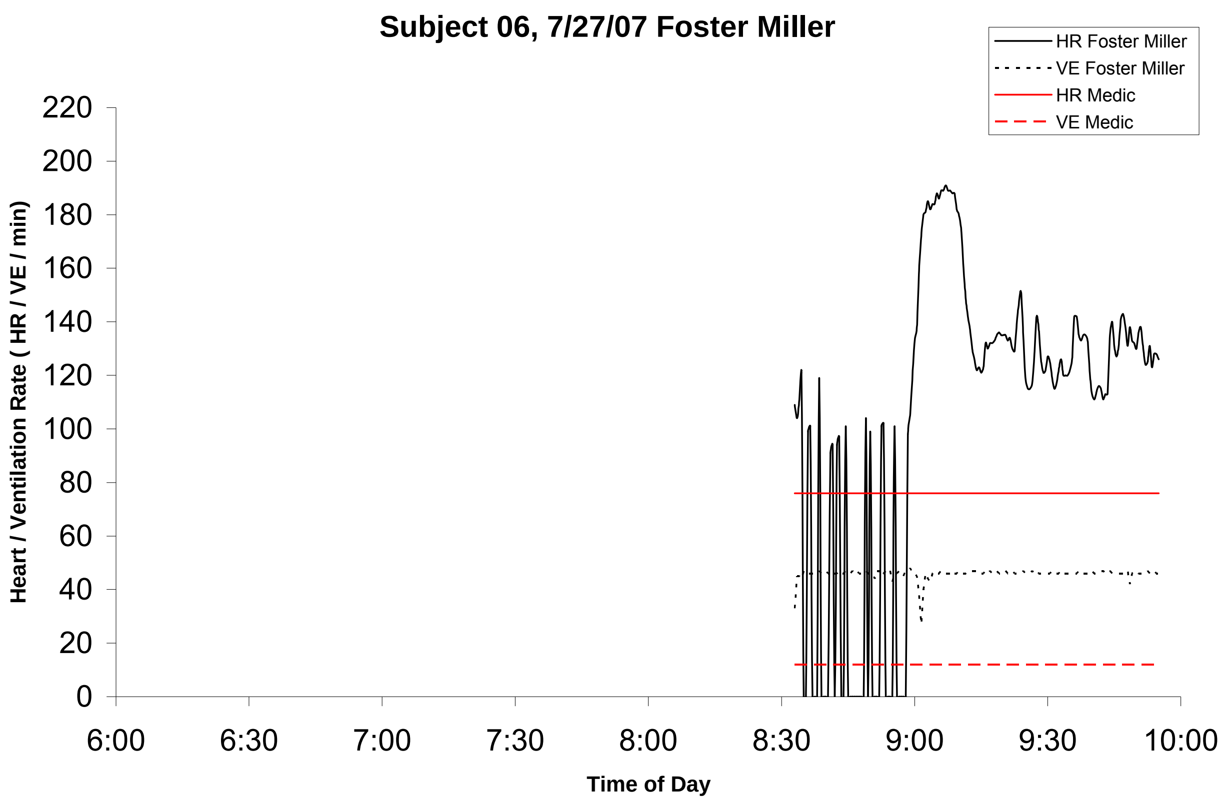
*Hidalgo System was removed prematurely by technician.

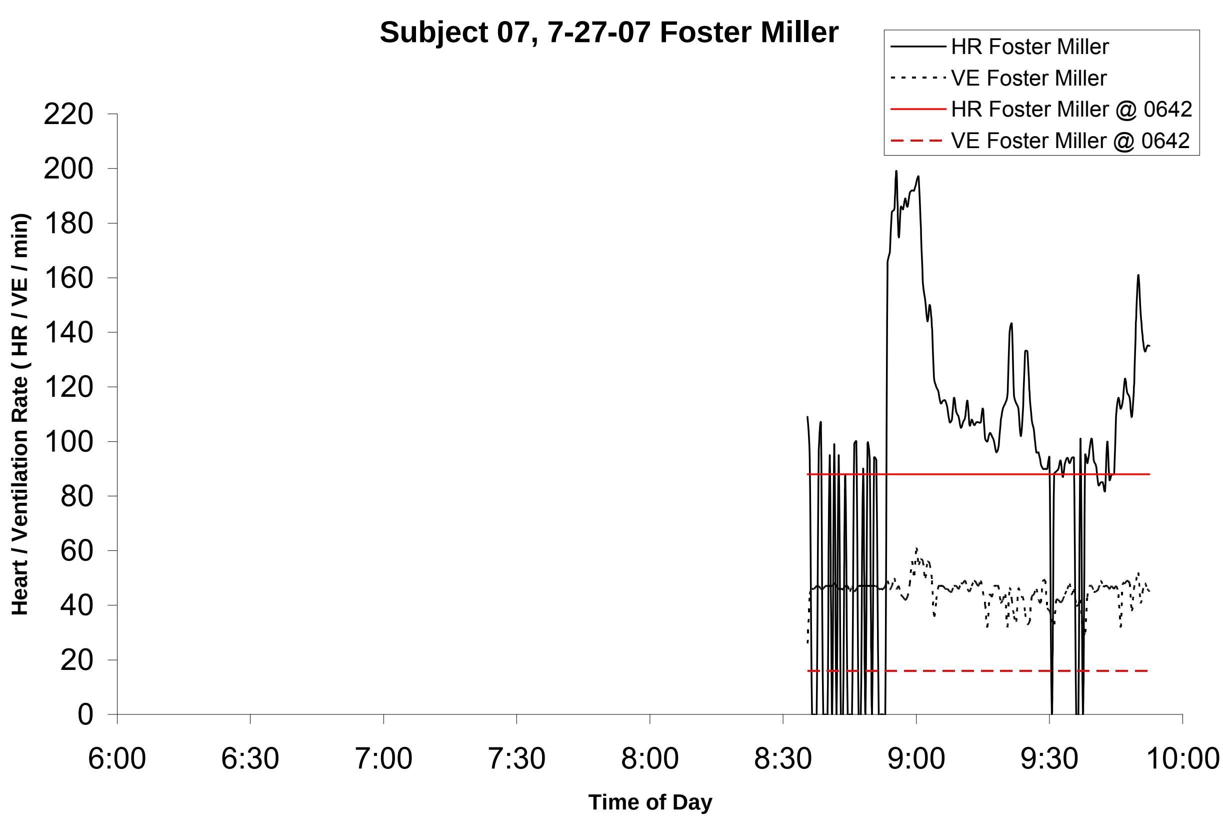


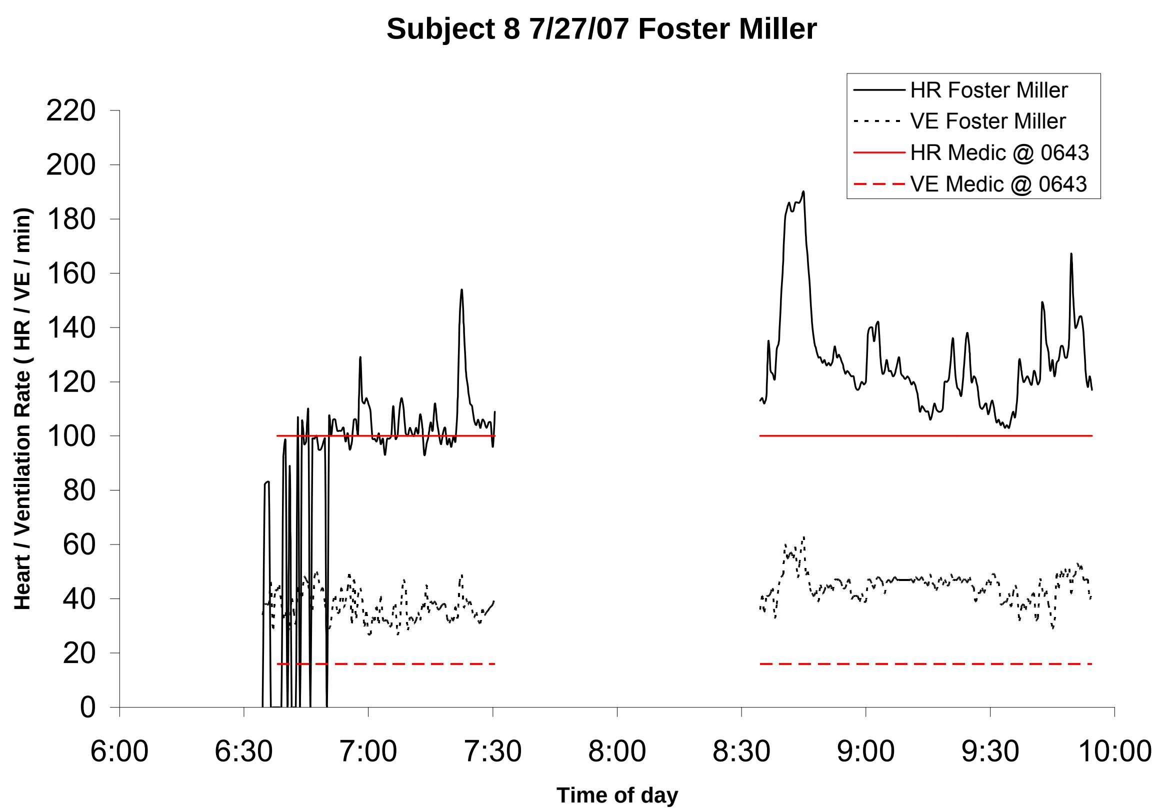
Subject 04, 7/24/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0639
VE Medic @ 0639
Heart / Ventilation Rate (HR / VE / min)
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day

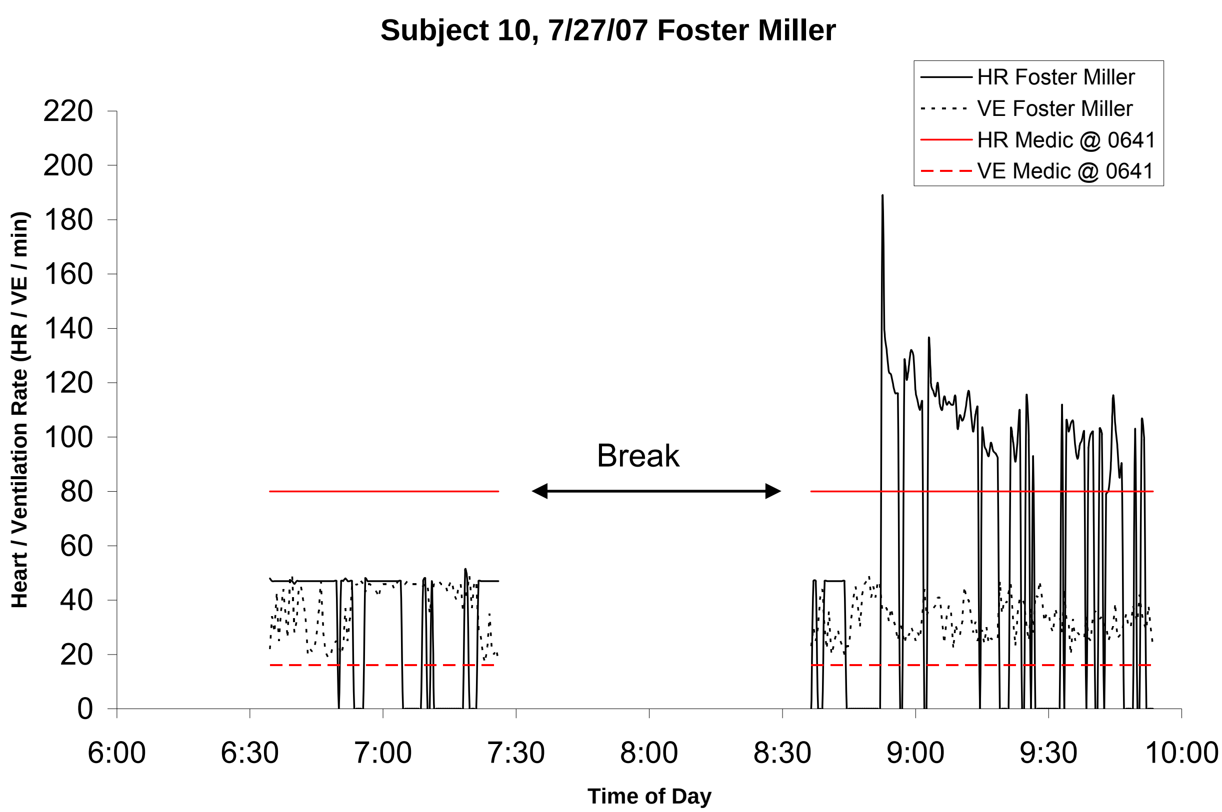


Subject 05, 7/27/07 Hidalgo
HR Hidalgo
VE Hidalgo
HR Medic @ 0639
VE Medic @ 0639
Heart / Ventilation Rate (HR / VE / min)
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 06, 7/27/07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Medic
VE Medic
Heart / Ventilation Rate (HR / VE / min)
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 07, 7-27-07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Foster Miller @ 0642
VE Foster Miller @ 0642
Heart / Ventilation Rate (HR / VE / min)
0
20
40
60
80
100
120
140
160
180
200
220
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day


Subject 8 7/27/07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Medic @ 0643
VE Medic @ 0643
Heart / Ventilation Rate (HR / VE / min)
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of day


Subject 10, 7/27/07 Foster Miller
HR Foster Miller
VE Foster Miller
HR Medic @ 0641
VE Medic @ 0641
Heart / Ventilation Rate (HR / VE / min)
Break
220
200
180
160
140
120
100
80
60
40
20
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
Time of Day